Europa Clipper Mission Concept Reconnaissance Working Group progress

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Outline

- Background
- Landing site requirements
- Updates to Reconnaissance traceability matrix
- Reconnaissance justification document
- Landform description
- F7 reconnaissance targets
- Proposed steps for Iteration 7

Background: Programmatic need for feed-forward Reconnaissance data sets from the Europa Clipper mission concept

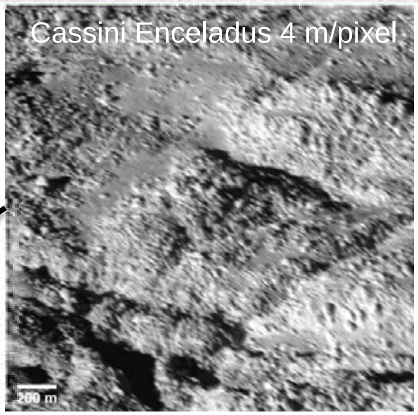
- Reconnaissance data is necessary from both science and engineering perspectives:
  - *Engineering reconnaissance for landing safety*
    - Is a safe landing site (within a lander's design margins) accessible to a spacecraft?
    - Assess at least 15 sites to determine conditions and find two that are safe
  - *Science reconnaissance for landing site selection (enabled by the current model payload)*
    - Is the landing site scientifically compelling in addressing the goal of exploring Europa to investigate its habitability?

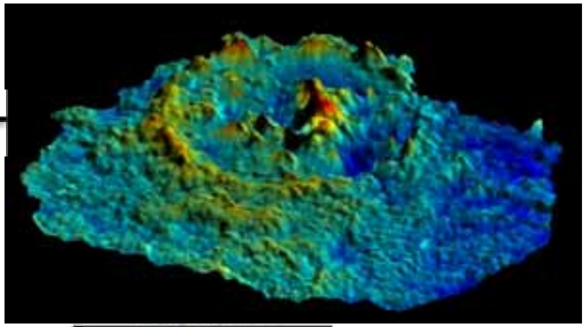
Highest Resolution Europa image currently available

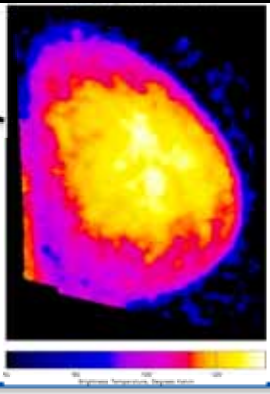
Background: Programmatic need for feed-forward Reconnaissance data sets

- Types of data required for landing safety

Observation	Purpose
High-resolution Imaging	- Map block abundance - Characterize ≥ meter-scale surface roughness
Stereo imaging	- Map surface slopes for lander tilt hazard, terrain relative navigation
Thermal IR Imaging (Brightness temperature and Bolometric albedo)	- Verify visible block abundance & extrapolate to submeter scale - Validate average surface roughness & extrapolate - Identify regolith cover







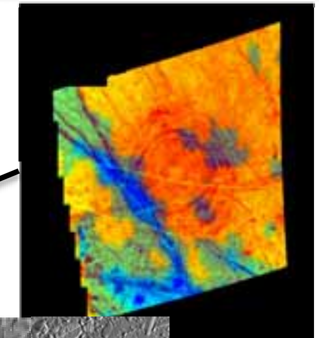
Galileo PPR

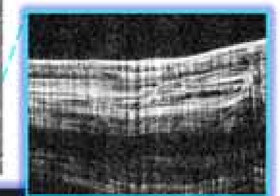
- Engineering reconnaissance capabilities would also provide additional data for the landing site scientific rationale

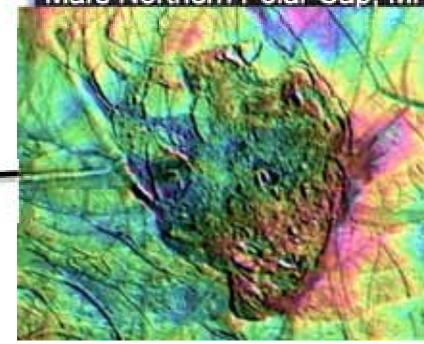
Background: Programmatic need for feed-forward Reconnaissance data sets

- Types of data required for selecting a scientifically compelling landing site

Observation	Purpose
Spectroscopic imaging	- Identify sites of compositional interest for habitability - Identify concentration and local variability, ocean representation, and recent extrusion
Context imaging	- Provide context to global scale geologic processes - Identify sites of recent geologic activity, relation to subsurface extrusions and upwelling
Sounding radar	- Identify sites proximal to shallow liquid water and potential for recent extrusion of ocean material
Stereo imaging (context and high-resolution)	- Understand the relative uplift and subsidence processes that relate the site to subsurface exchange - Characterize local slopes that drive mass movement and landform development





Reconnaissance Justification Document

One of the major tasks in this iteration was the preparation of a document which justifies each requirement in the RTM. We discuss the reasoning behind the engineering and science requirements, and include relevant references. This document is in review.

Reconnaissance Traceability Matrix

- The Reconnaissance traceability matrix (RTM) has been scrubbed and modified as follows:
  - Two investigations have been merged
  - The measurement requirements have been placed into a simplified form
  - All landing safety and science measurements have been prioritized

Europa Reconnaissance Traceability Matrix									Priority	Areal coverage (km)		Incidence angle range (degrees)		Spatial resolution (m/pixel)		Local time of day range (hr)		Spectral characteristics	Coincident instrument
Goal		Objective		Investigation		Measurement	Short name	Model Instrument		Baseline	Floor	Baseline	Floor	Baseline	Floor	Baseline	Floor		Baseline
aracterize Safe and Scientifically Compelling Sites for a Lander Mission to Europa	acterize the Safety of Landing Sites on Europa	Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness.	SL.1	Determine the distribution of blocks and other roughness elements within a potential landing site at scales that represent a hazard to landing.	SL.1a	Measure the occurrence and lengths of shadows cast by blocks protruding 1 m or more above the surface, and the abundance and nature of surface roughness elements at scales from >10 m to <1 m, through monochromatic imaging at a spatial resolution on the surface of <=0.5 m/pixel.	Blocks	Reconnaissance Camera (RC)	R1	5x10	2x10	45-70	20-80	0.5	0.5			Monochrome	
					SL.1b	Characterize the fractional area of block coverage and the areal distribution of roughness elements by measuring the contrast in thermal emission between at least 2 spectral channels (with less than 80% overlap) at local times of day between 10 AM and 3 PM and at a spatial resolution on the surface of <= 250 m/pixel.		Thermal Imager (ThI)	R2	5x10	2x10			<250	<250	10-3 pm	10-3 pm	2 spectral channels <80% overlap	Recon camera
			SL.2	Determine the distribution of slopes within a potential landing site over baselines relevant to a lander.	SL.2a	Measure surface slopes of up to 25° on a 3 m baseline for all azimuths by acquiring stereo paired images with a spatial resolution of <=0.75 m/pixel.	Slopes	Reconnaissance Camera (RC)	R1	5x10 (>90% cross- and down-track overlap)	2x10 (>90% cross- and down-track overlap)	20-70 (each pair); 15-30 convergence angle		<0.75	<0.75			Monochrome	
					SL.2b	Characterize the statistical distribution of slopes from nadir track altimetric information having a relative height accuracy of 1 m.		Ice Penetrating Radar (IPR)	R3	SAME AS SCIENCE TRACEABILITY MATRIX*									Recon camera
			SL.3	Characterize the regolith cohesiveness and slope stability within a potential landing site.	SL.3a	Determine the regolith-component thermal inertia of the upper decimeter-scale surface layer by measuring the contrast in thermal emission between at least 2 spectral channels (with less than 80% overlap) at local times of day between 10 AM and 3 PM and at a spatial resolution on the surface of	Regolith cohesion	Thermal Imager (ThI)	R3	SAME AS 1B									

Summary RTM

Europa Reconnaissance Traceability Matrix				
Goal		**Objective**		**Investigation**
Select a Safe and Scientifically Compelling Site for a Lander Mission to Europa	**SL. Characterize the Safety of Landing Sites on Europa**	Assess the distribution of surface hazards, the load-bearing capacity of the surface, the structure of the subsurface, and the regolith thickness.	SL.1	Determine the distribution of blocks and other roughness elements (e.g., scarps, steps, cracks, divots, cusps, spires, etc.) within a potential landing site at scales that represent a hazard to landing.
			SL.2	Determine the distribution of slopes within a potential landing site over baselines relevant to a lander.
			SL.3N	Characterize the regolith cohesiveness and slope stability within a potential landing site.
			SL.4	Determine the regolith thickness and whether subsurface layering is present within a potential landing site.
	SV. Characterize the Scientific Value of Landing Sites on Europa	Assess the composition of surface materials, the geologic context of the surface, the potential for geologic activity, the proximity of near surface water, and the potential for active upwelling of ocean material.	SV.1	Characterize the composition and chemistry of potential landing sites with an emphasis on understanding the spatial distribution and degradation state of endogenically-derived compounds.
			SV.2	Characterize the potential for recent exposure of subsurface ice or ocean material and resurfacing vs. degradation of the surface by weathering and erosion processes and provide geologic context for potential landing sites.
			SV.3	Characterize the potential for shallow crustal liquid water beneath or near potential landing sites.
			SV.4	Characterize anomalous temperatures (that which are significantly out of equilibrium with expected nominal diurnal cycles) indicative of current or recent upwelling of ocean material at or near potential landing sites

Measurement prioritization

- It would likely be challenging to operate the entire payload and acquire all possible data during low-altitude flybys
- Some data types are of lower priority, and are more challenging to acquire
- As a result, Reconnaissance measurements have been prioritized such that they can be woven into the operations plan or descoped if necessary
- We have prioritized the RTM measurements for both science and landing safety, based on the assumption that landforms of the same type will have similar characteristics regardless of where on Europa’s surface they appear

Measurement prioritization

- **R1: Highest priority**
  - Required: Fully characterize 15 sites containing landforms of high scientific interest (to be chosen ahead of time, with additional sites for margin). Acquire for floor measurement ellipses (2 x 10 km)
  - Desired: Acquire for baseline measurement ellipses (5 x 10 km).
  - *R1 measurements include RC and SWIRS*
- **R2: Medium priority**
  - Required: Characterize all major landform types
  - Desired: Acquire over all candidate floor (2 x 10 km) landing ellipses
  - *R2 measurements include RC, ThI, TI, IPR*
- **R3: Lowest priority**
  - Acquire on a best-effort basis
  - *R3 measurements include RC, IPR, ThI*

What constitutes a “landform”?

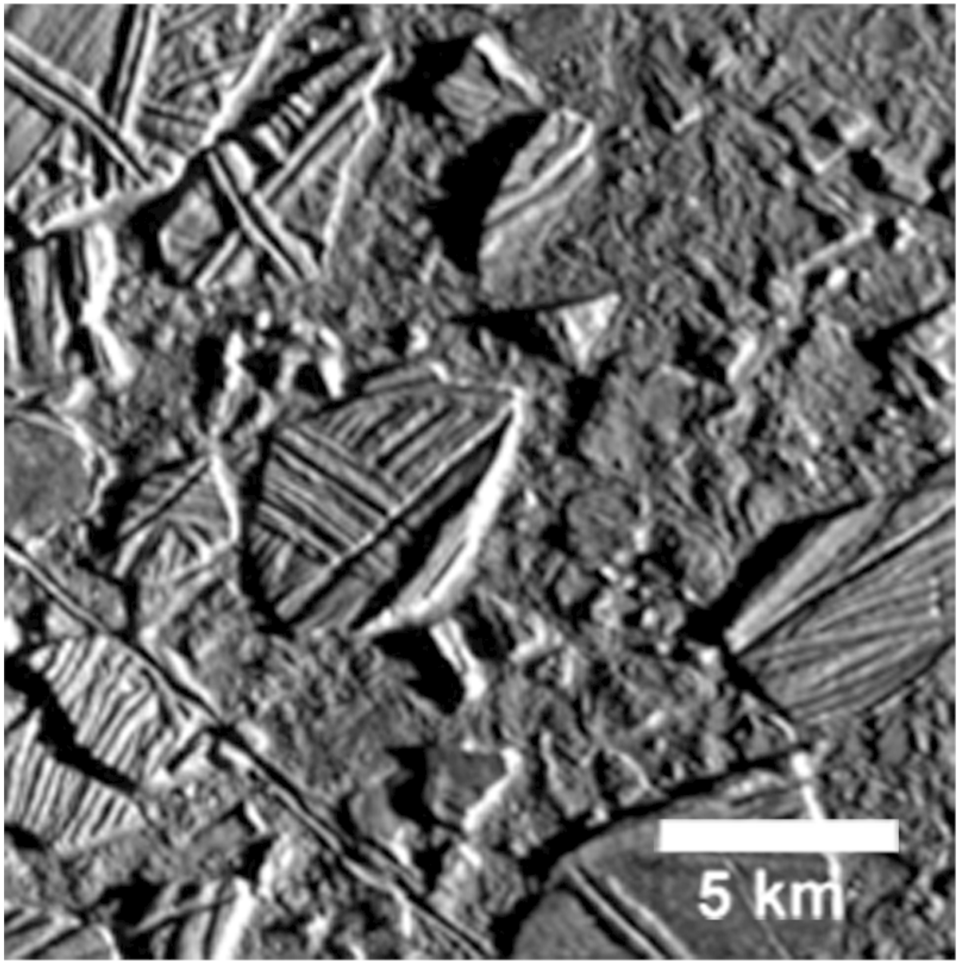
The RTM commonly refers to “landforms” as a measurement priority. Principle landforms of interest are:

- Chaos
- Lenticulae
- Dark plains
- Ridges
  - Double ridges
  - Ridge complexes
- Bands
  - Lineated bands
  - Smooth bands
- Impact features

Highest priorities

Chaos

- Up to several tens of km in extent
- Characterized by polygonal blocks of ridged plains within a matrix of hummocky material
- May be low-lying or high-standing relative to the surrounding plains



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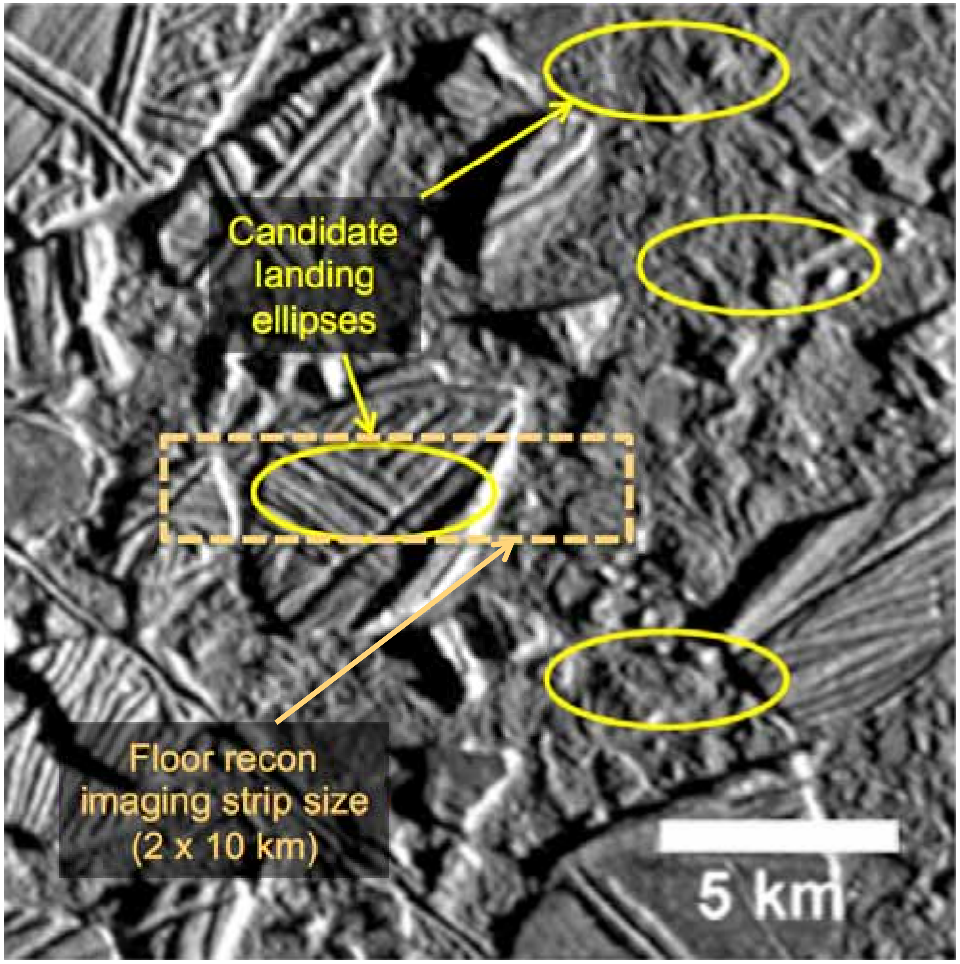
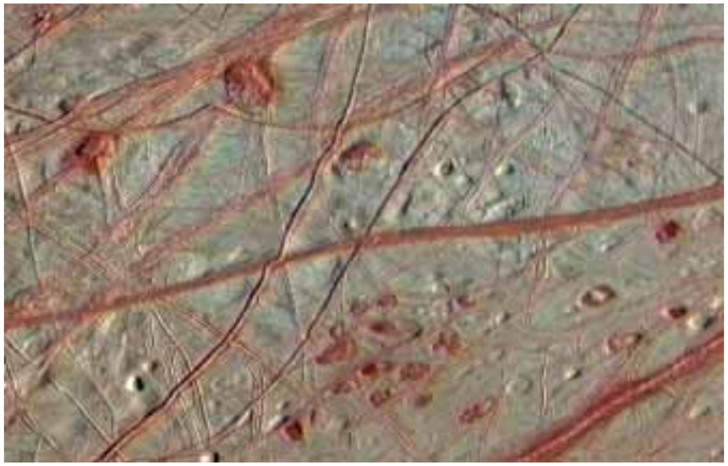
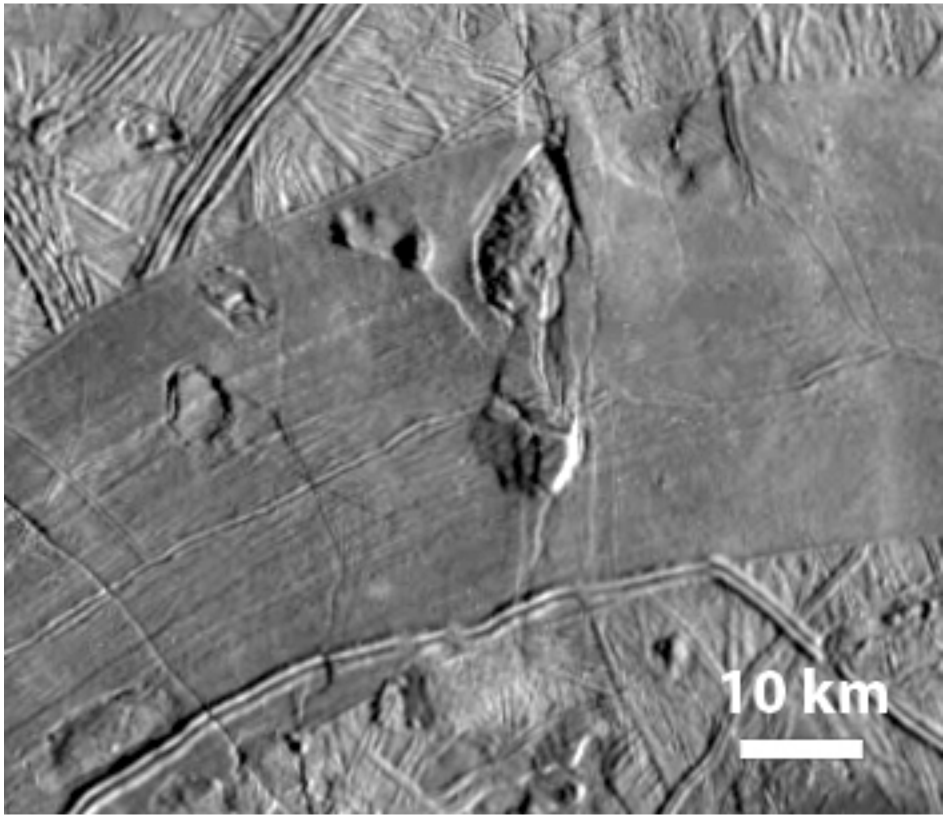


Lenticulae

- May be related to chaos
- Circular to elliptical features 10s to 100s of meters in relief
- Commonly 10-15 km in diameter
- May have positive topography (domes), negative (pits) or of low albedo (“spots”)
- Most pit-type lenticulae disrupt preexisting terrain with chaos-like materials





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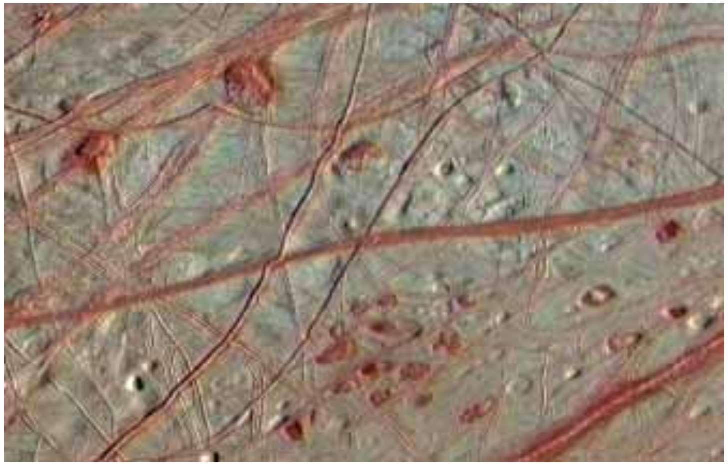
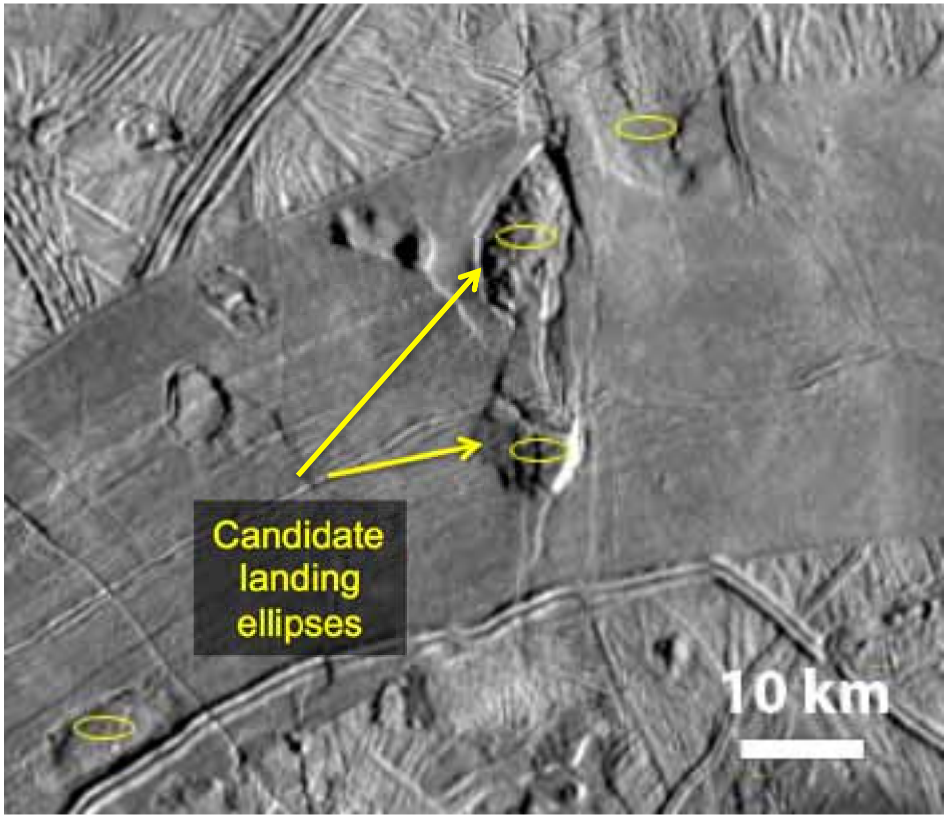
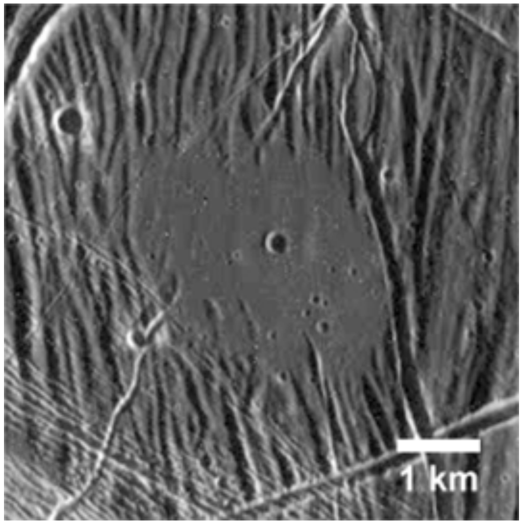
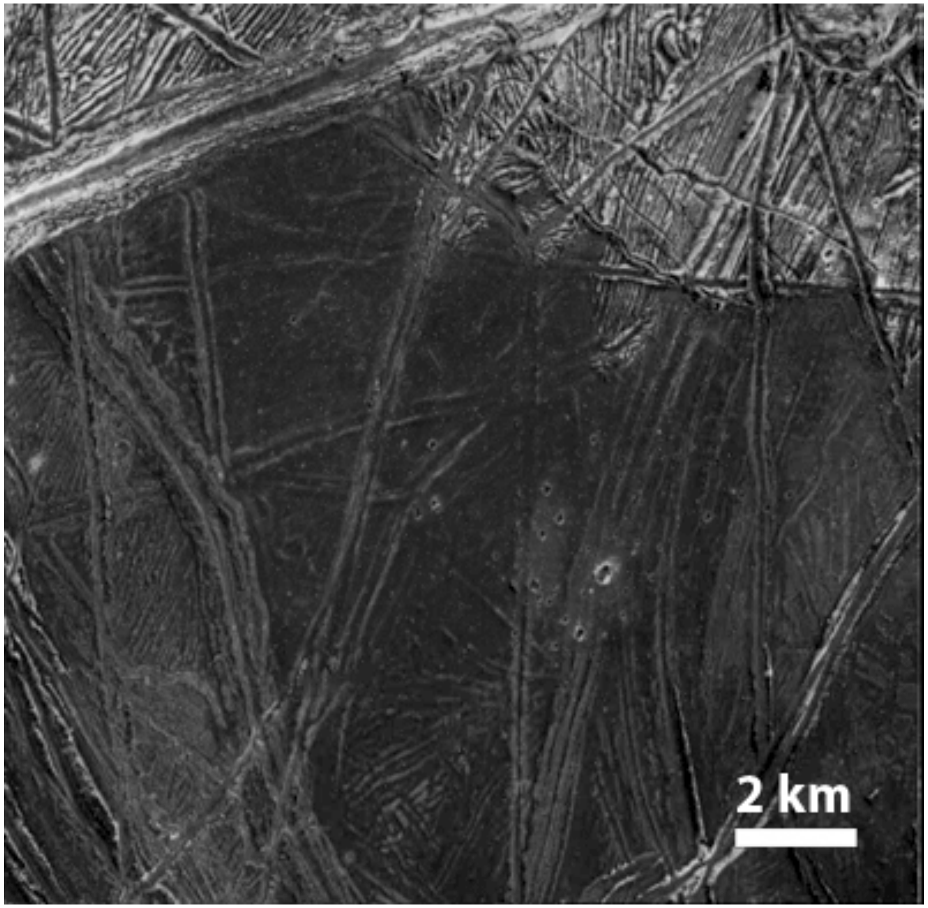




Dark plains

- Low-albedo material showing clear embayment relationships with the surrounding terrain
- Commonly associated with chaos and lenticulae





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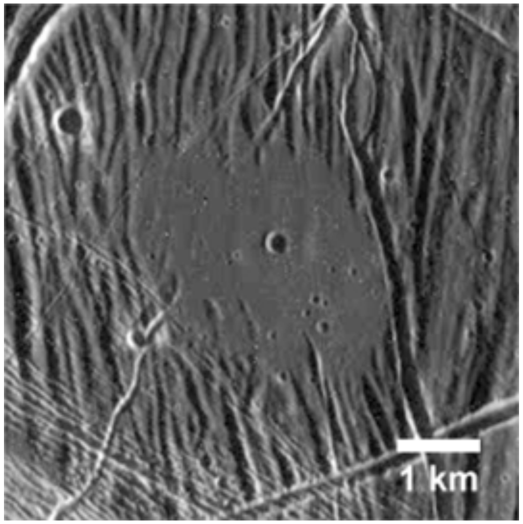
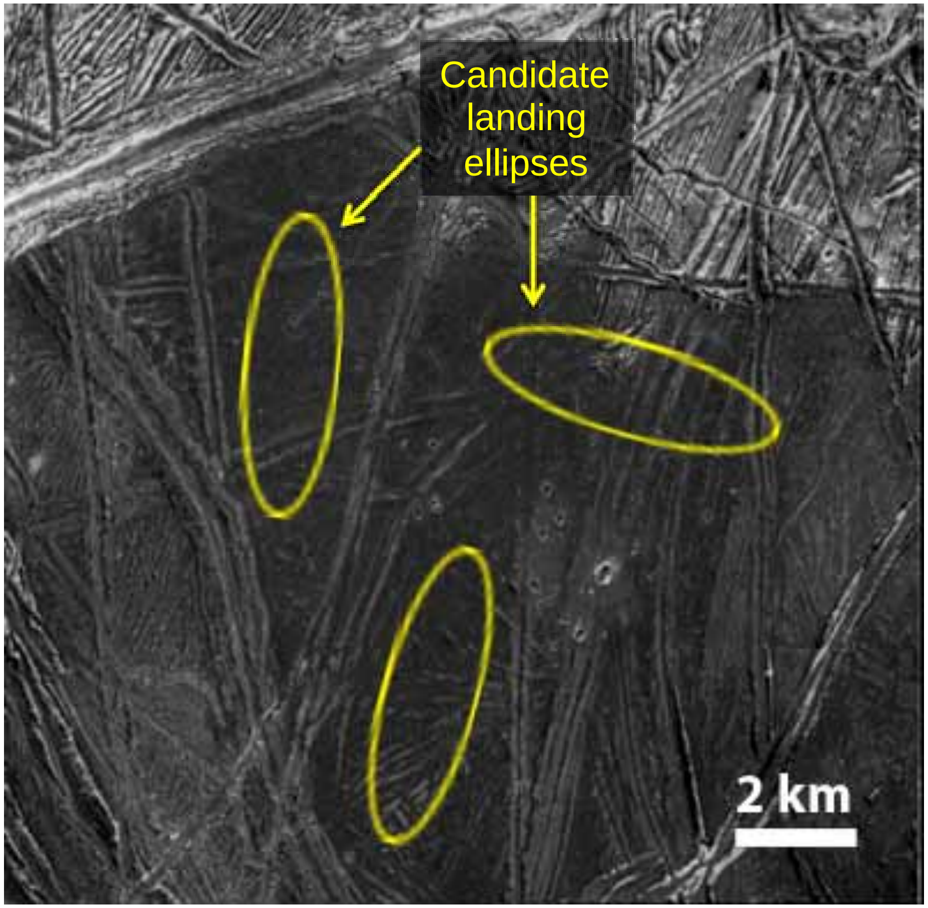
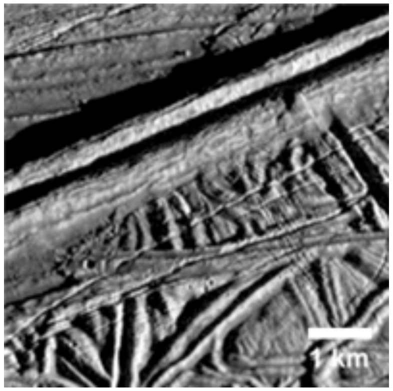
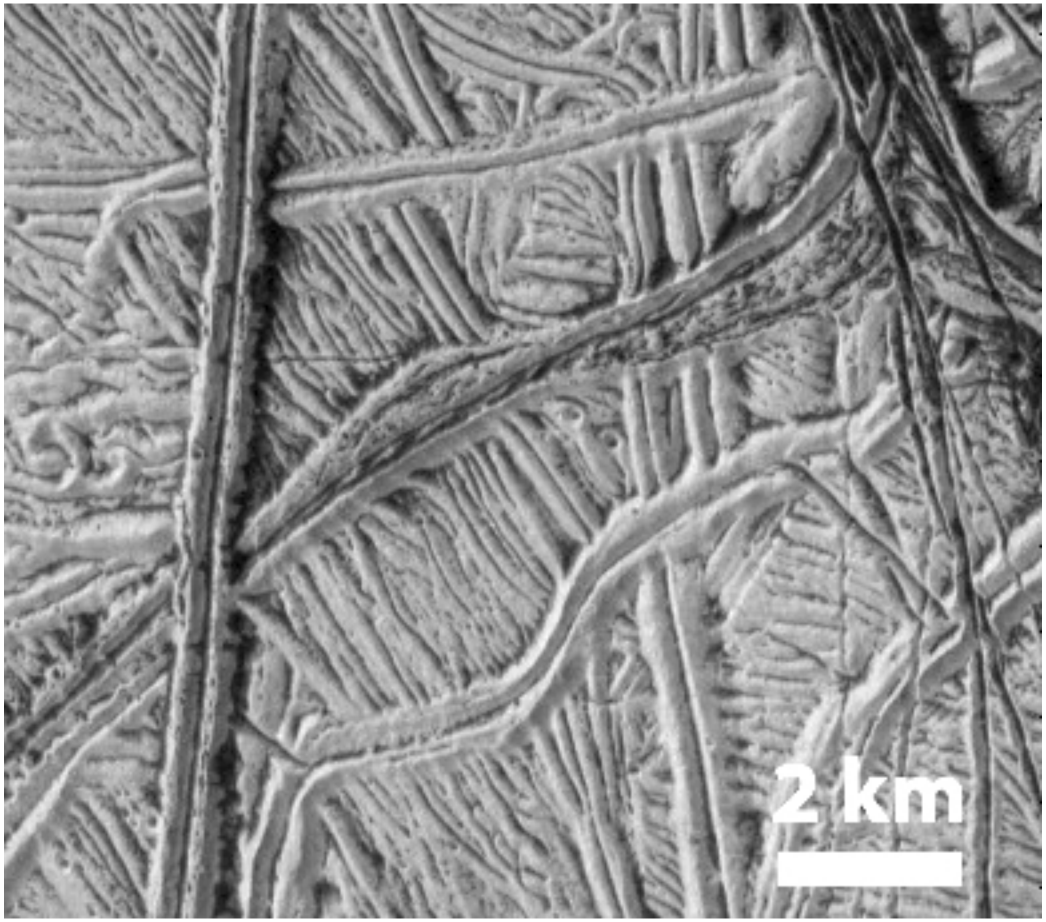




Double ridges

- Ridge pairs separated by a medial trough are Europa's most common landform
- Range in length from few km to >1000 km, 0.2 to >4 km wide
- Mass wasting along flanks
- May be cycloidal in planform





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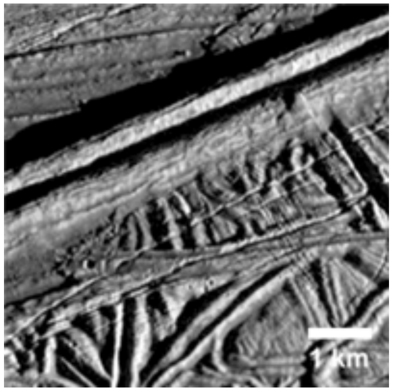
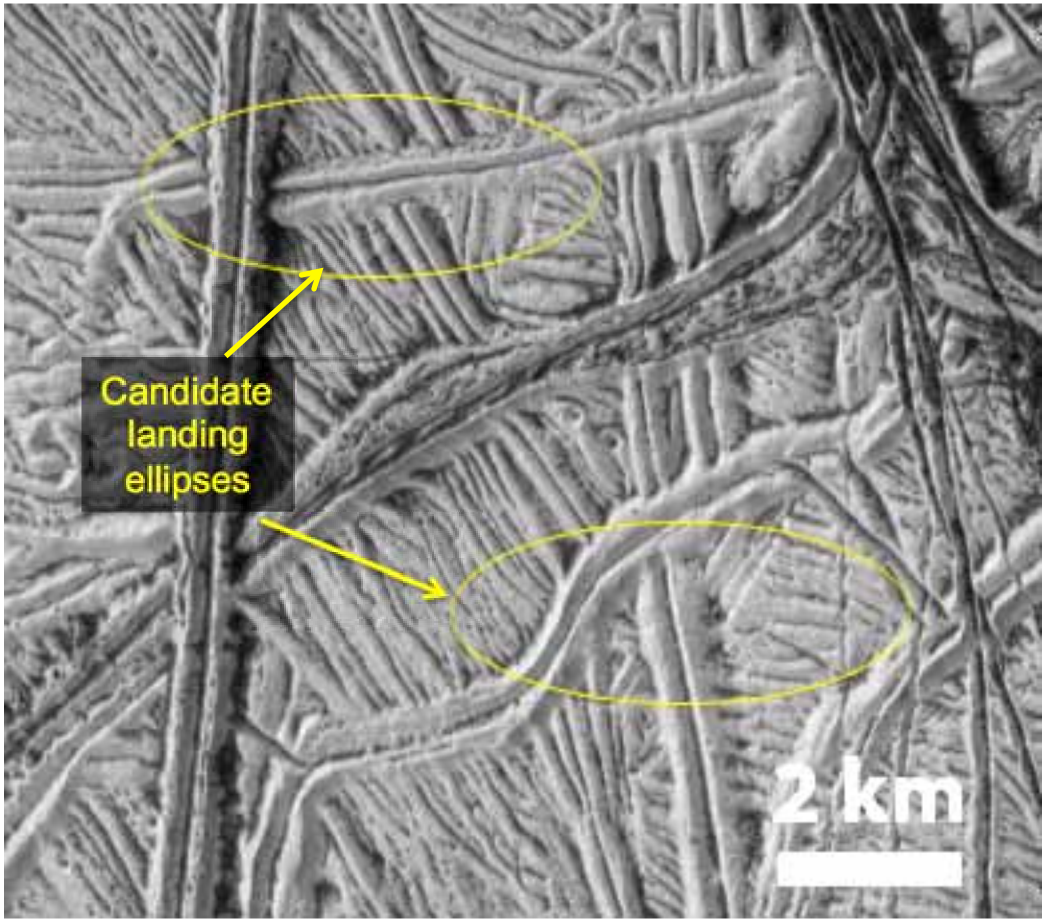
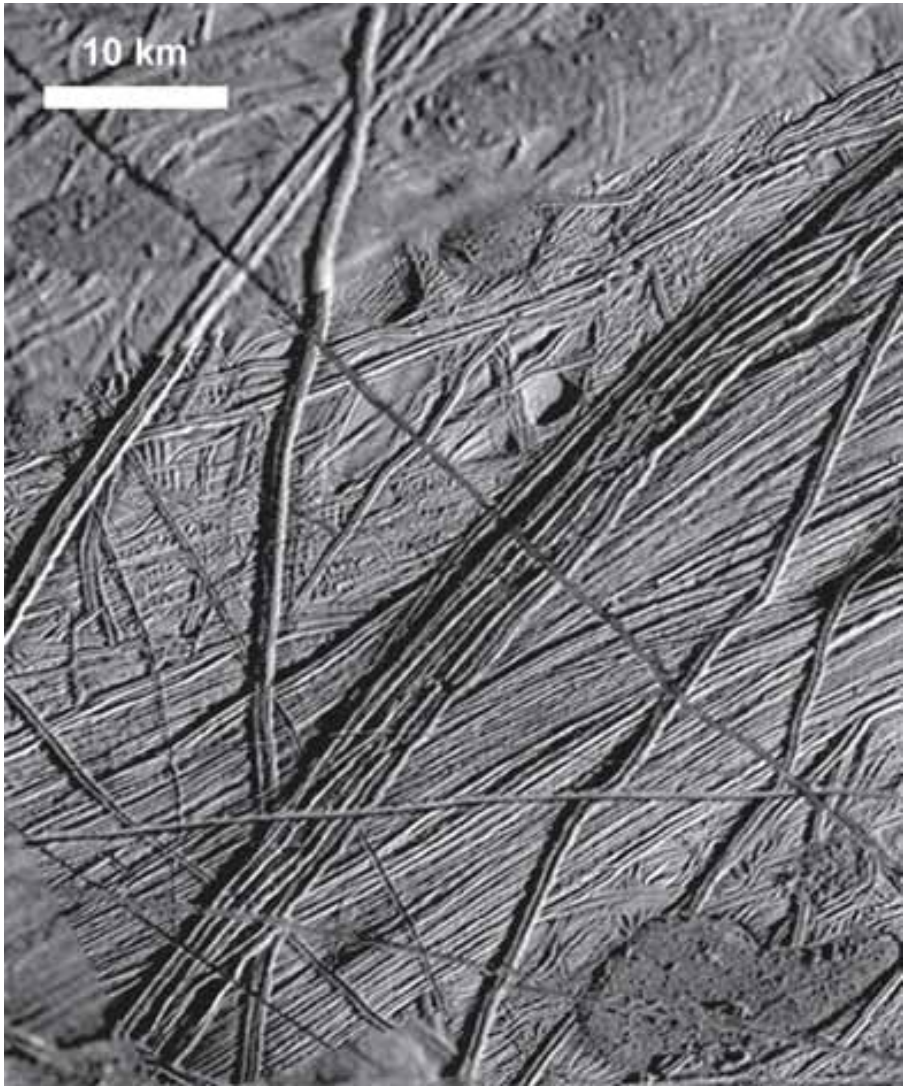




Ridge complexes

- Multiple subparallel anastamosing and inosculating single or double ridges
- Up to tens of km wide, many tens of kilometers long
- Linear to curvilinear with sinuous or undulating margins



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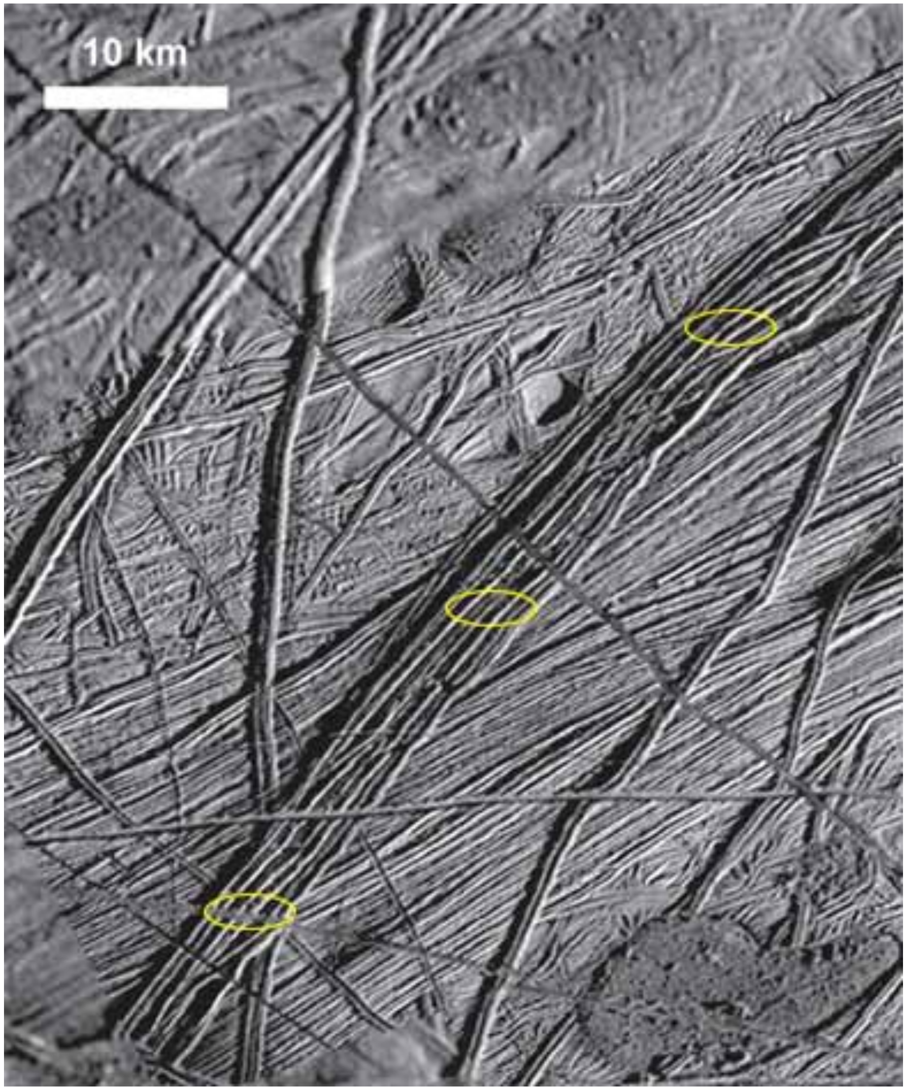
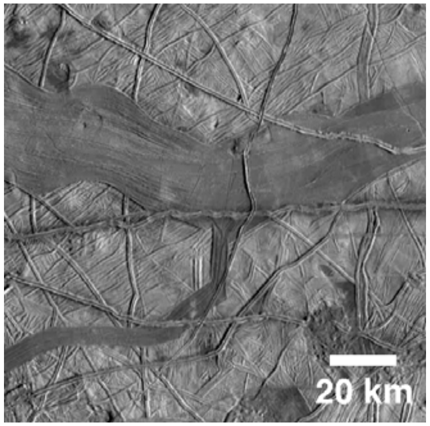
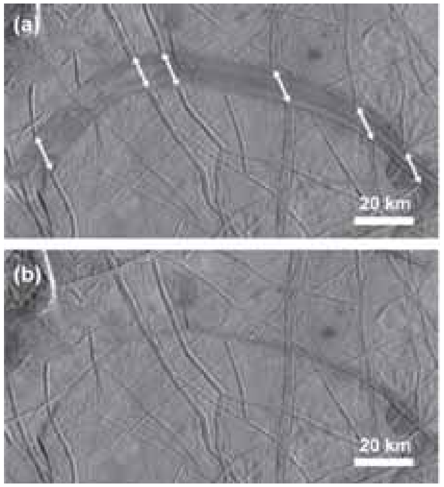
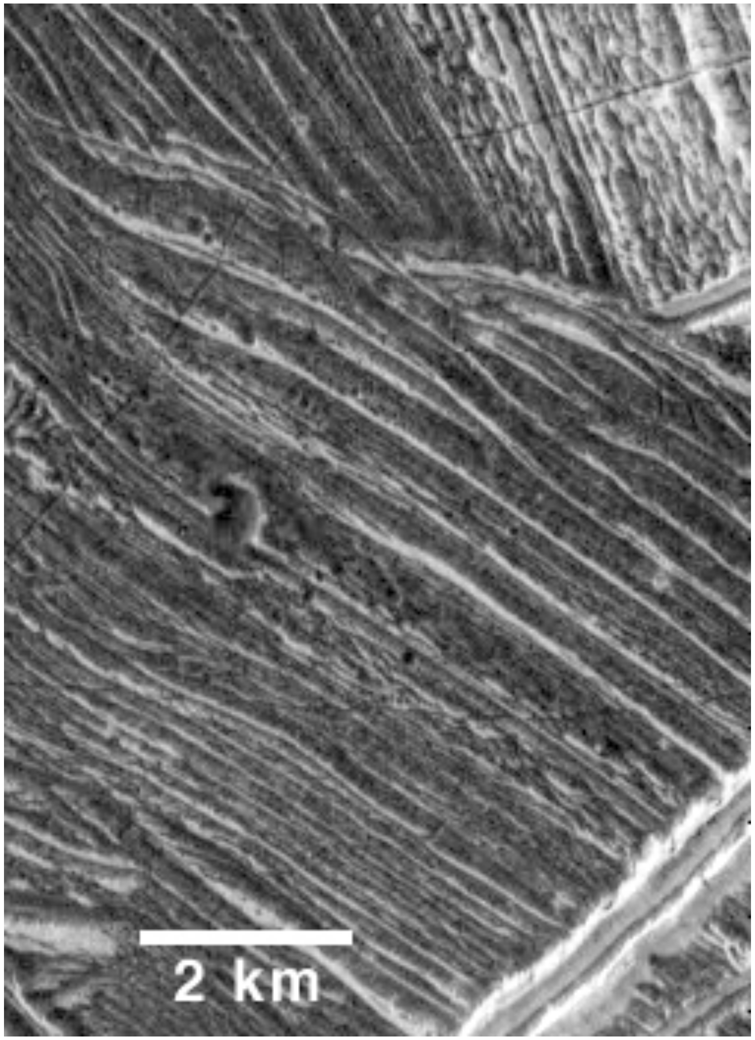


Lineated bands

- Up to 30 km wide, >100 km long
- Contrast in albedo and/or surface texture compared with the surrounding terrain
- Distinct margins, bounded by ridges
- Narrow central trough, internal structure of ridges and troughs trending subparallel to boundaries







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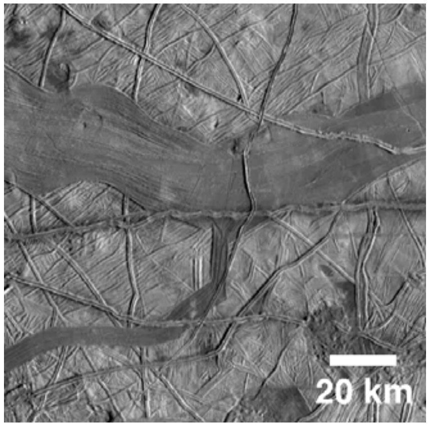
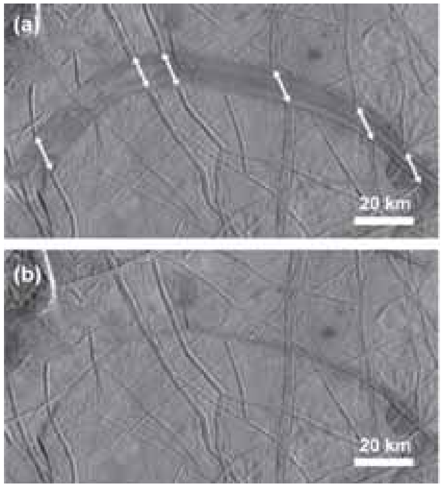
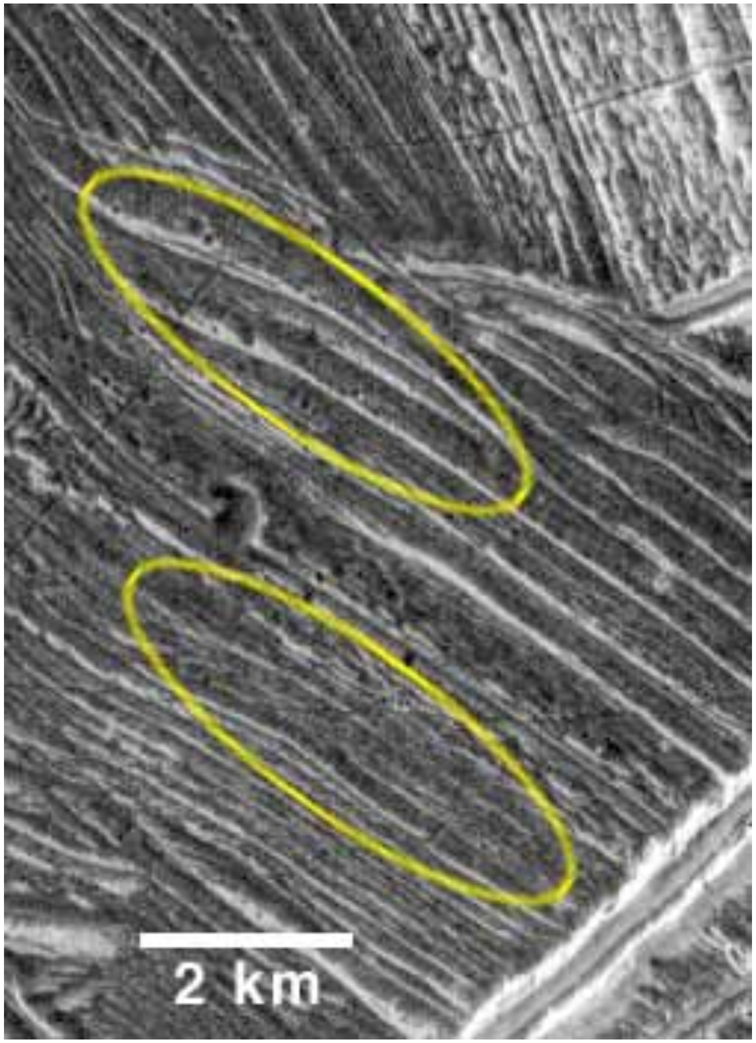
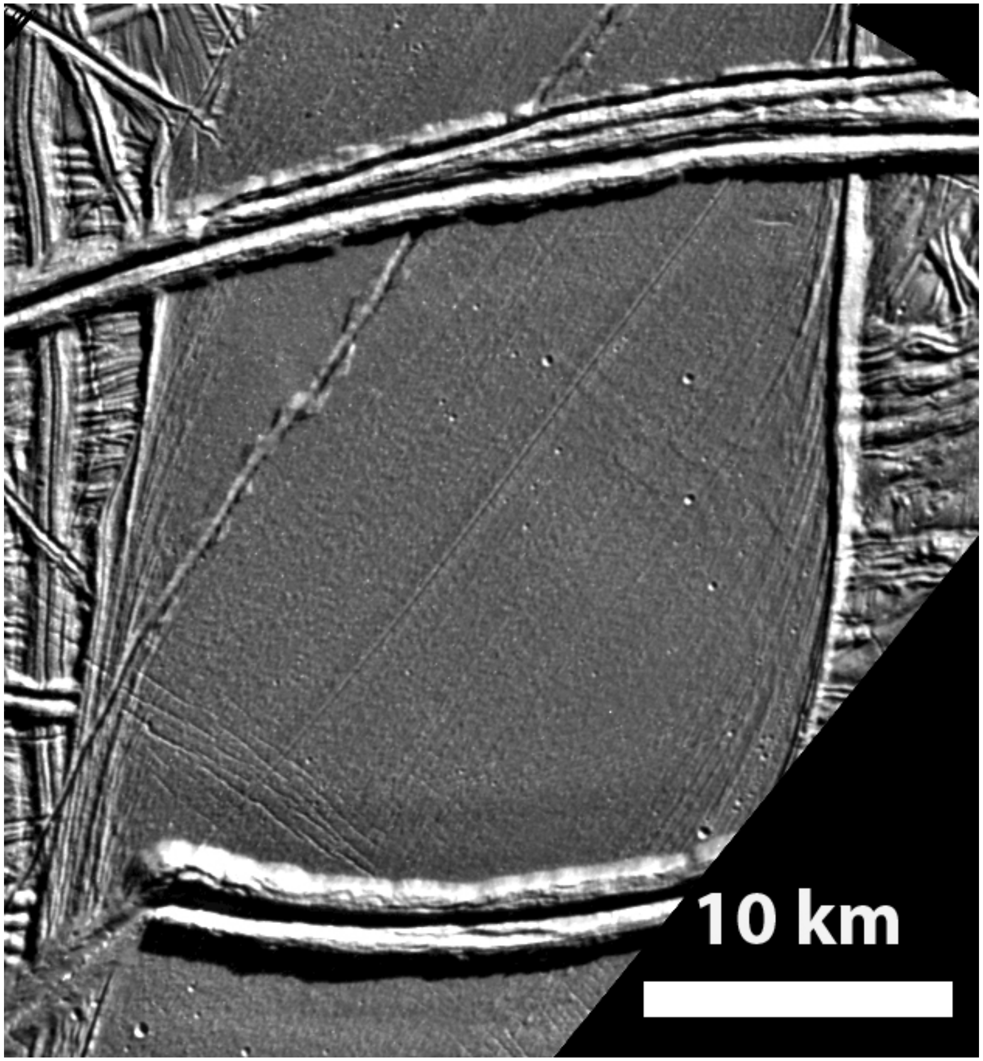






Smooth bands

- Same size and albedo characteristics as lineated bands
- Distinct margins, not bounded by ridges
- Narrow central trough, internal structure of hummocks trending subparallel to boundaries, may be fractured parallel to margins



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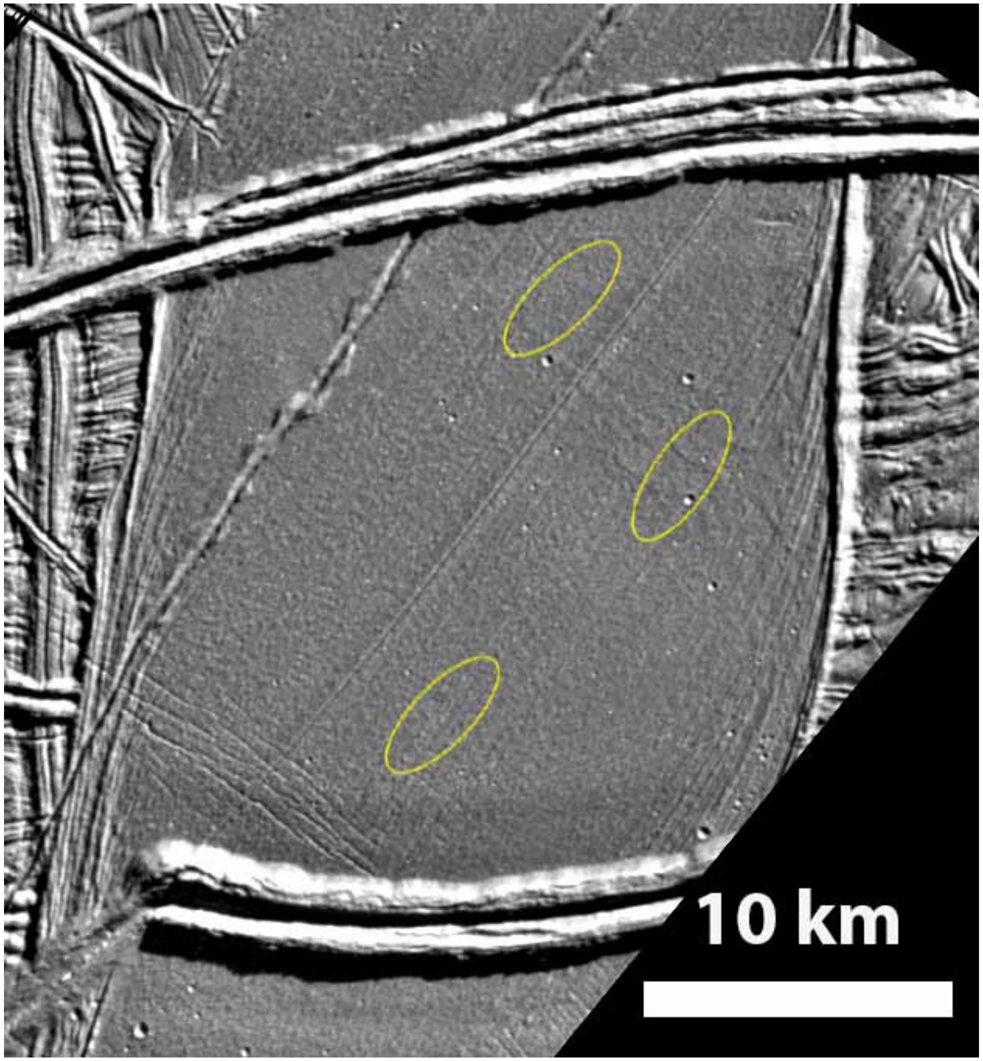
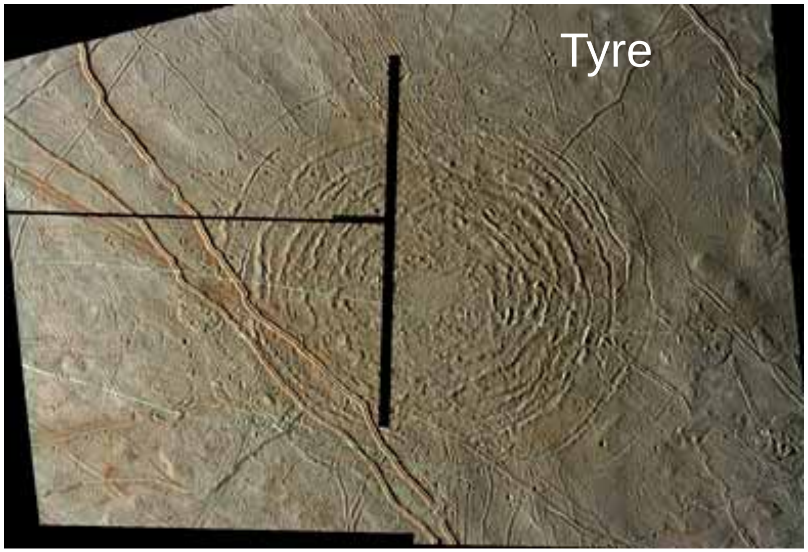
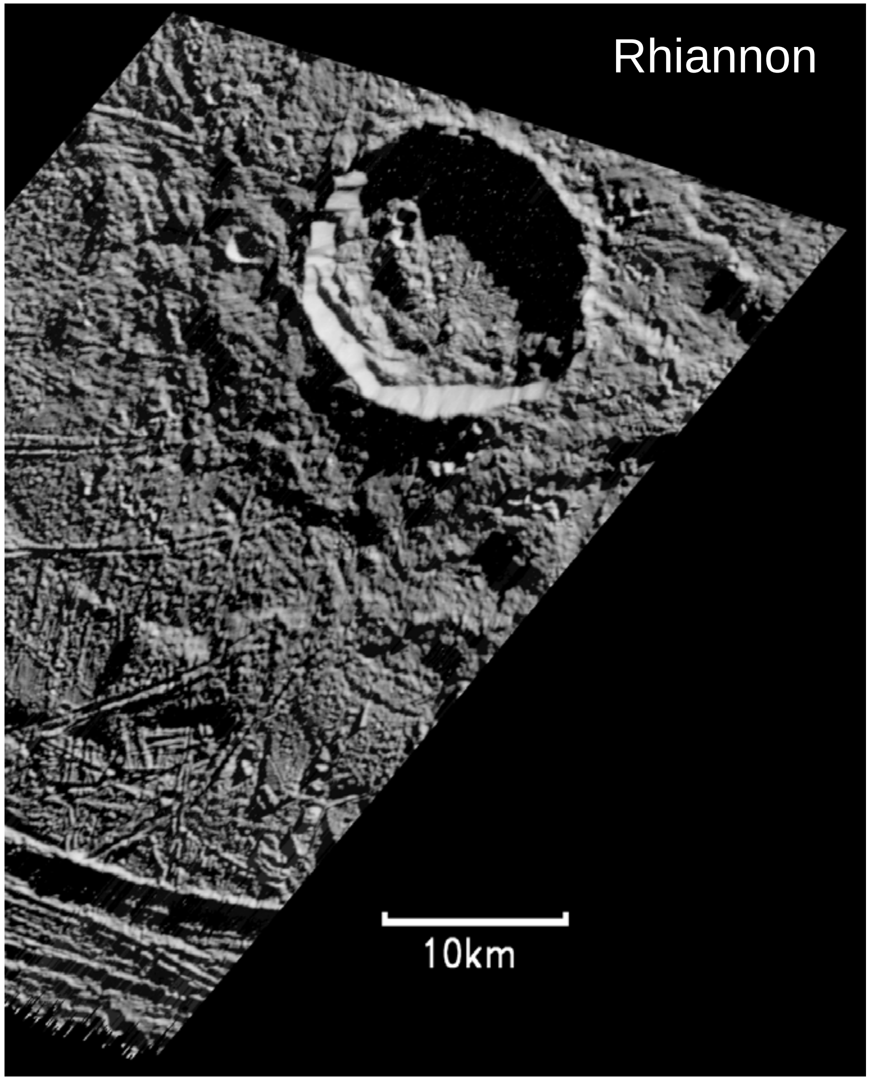


Impact features

- 28 impact features have been identified within the imaged regions of Europa's surface
- Named craters range from 4 – 45 km in diameter
- The largest, Tyre, is a multi-ring basin





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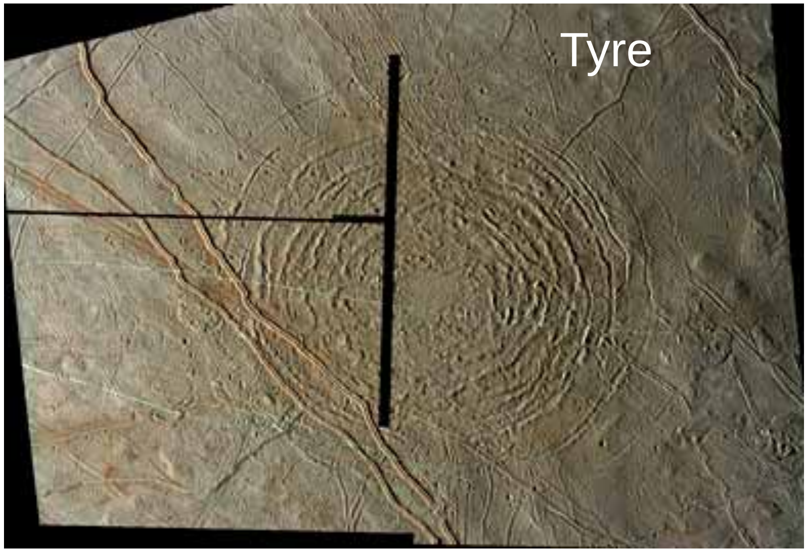
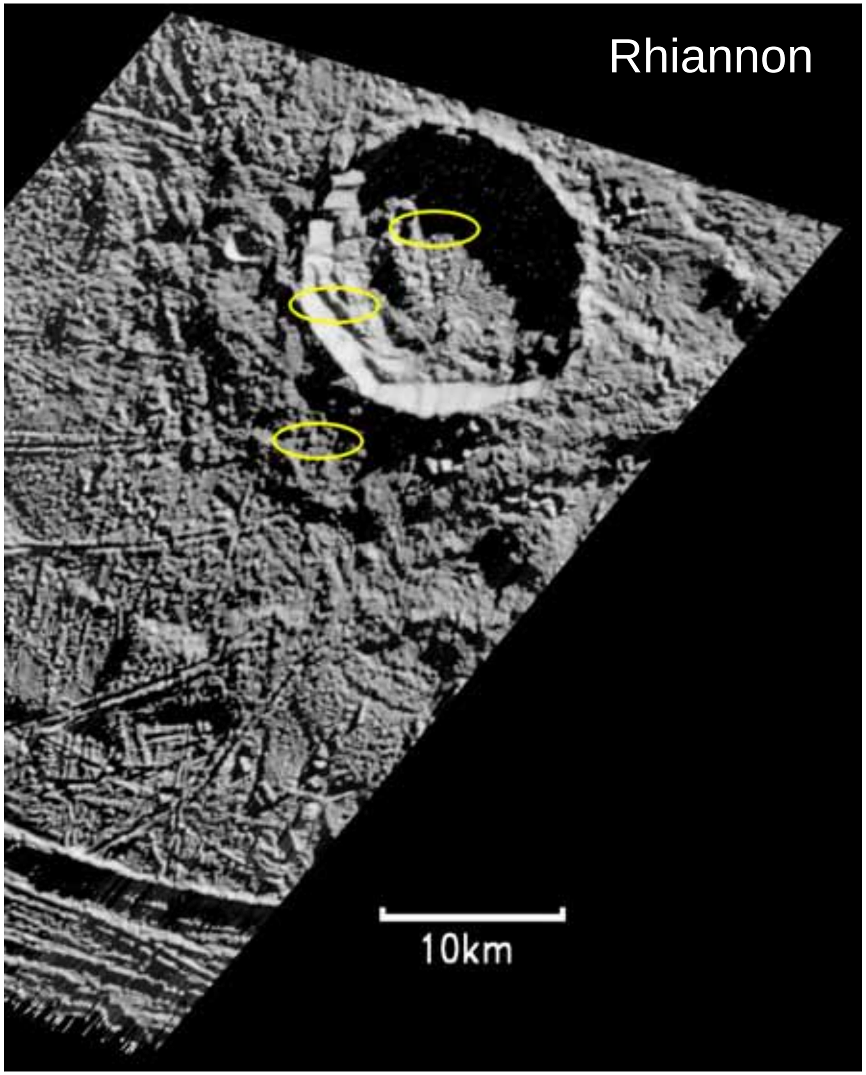
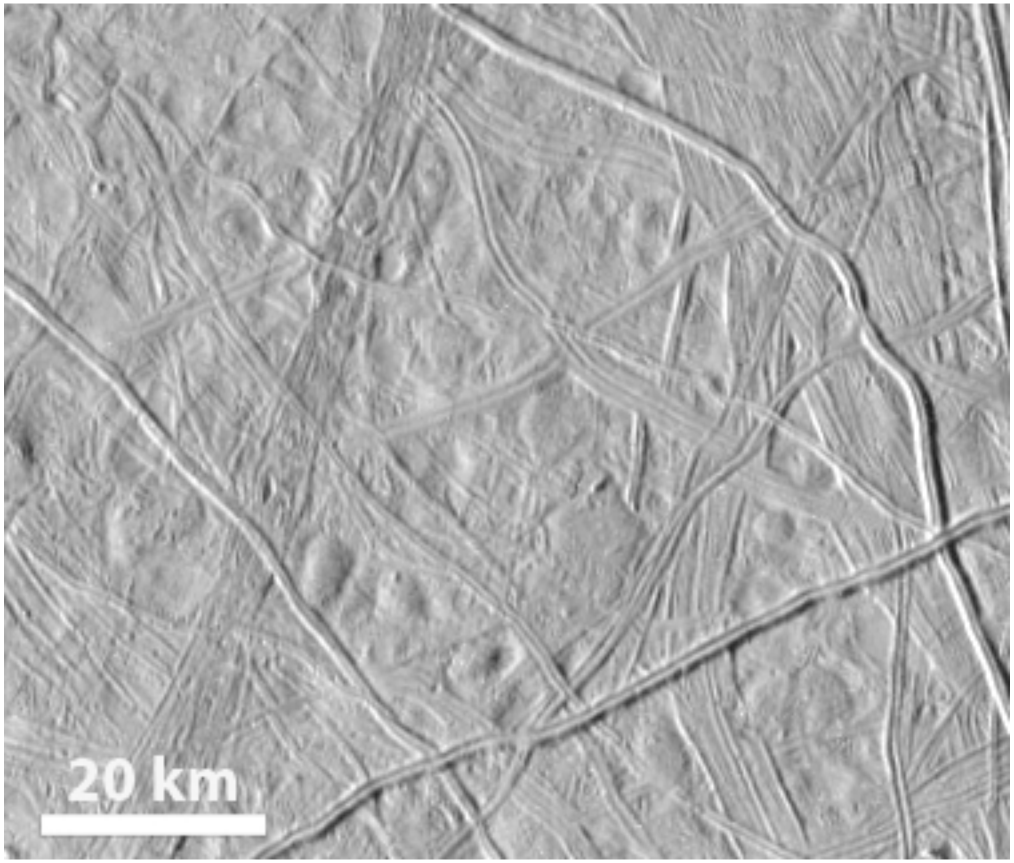




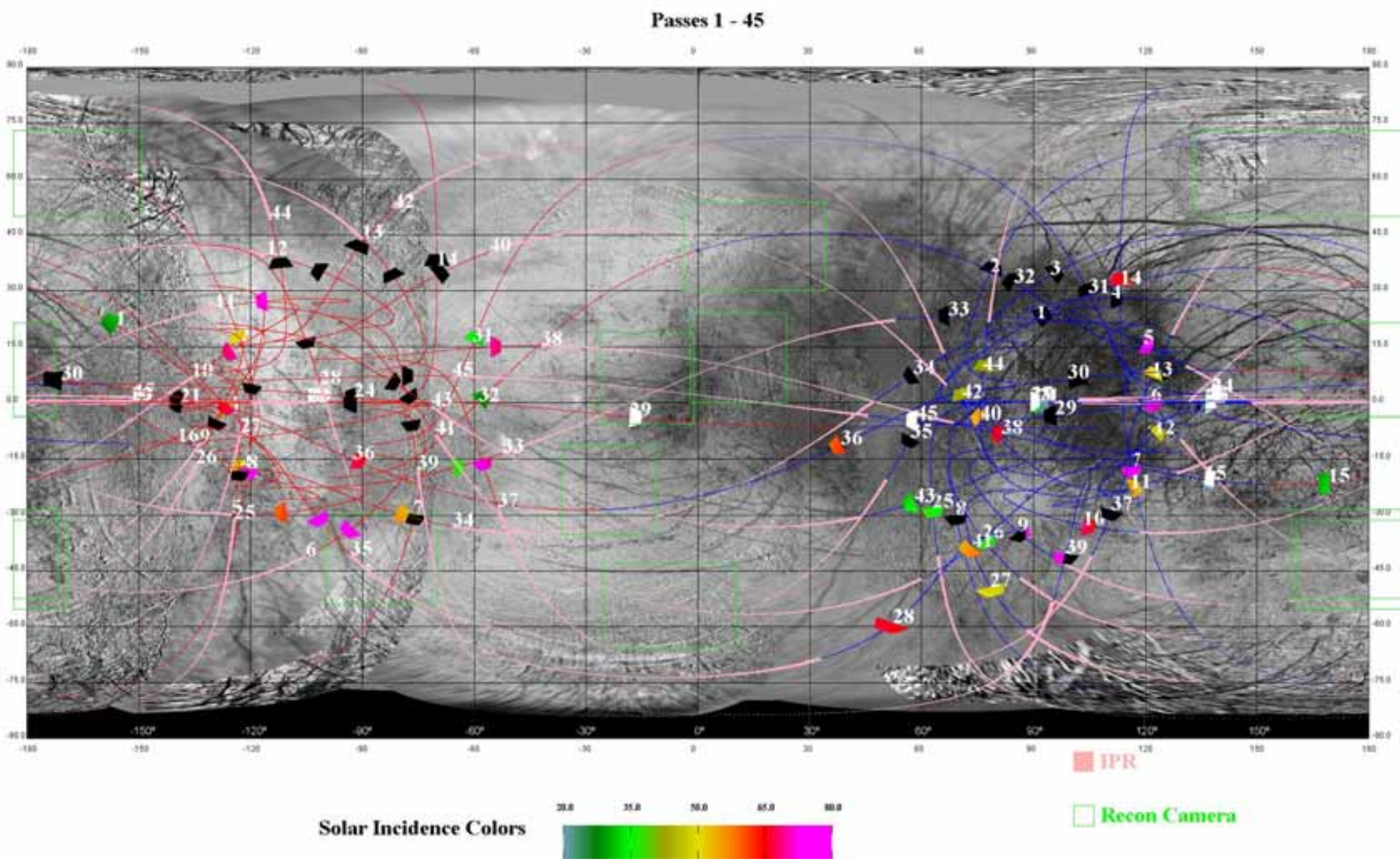
Widespread terrain type: Background ridged plains

- Not targeted (not considered a landform)
- Various morphology and states of degradation
- Oldest stratigraphic unit – probably longest exposure to space environment
- Bright, water-rich
- May hold evidence of Europa's past



Preliminary F-7 trajectory analysis

13-F7 All 45 Flybys (SWIRS, IPR, RC)



Reconnaissance Camera

Measurements

- SL.1a - Measure the occurrence and lengths of shadows cast by blocks protruding 1 m or more above the surface, and the abundance and nature of surface roughness elements at scales from >10 m to <1 m [R1].
- SL.2a - Measure surface slopes of up to 25° on a 3 m baseline for all azimuths [R1].
- SL.3b - Identify small scale landforms associated with mass movement [R3].
- SL.4b - Identify small scale landforms associated with exposed layers [R3].
- SV.2a - Identify small scale landforms diagnostic of the local geologic history of potential landing sites [R2].

Requirements

Monoscopic	Baseline	Floor
Areal Coverage (km)	5 x 10	2 x 10
Incidence Angle (°)	45 - 70	20 - 80
Spatial Resolution (m)	0.5	

Stereoscopic	Baseline	Floor
Areal Coverage (km)	5 x 10	2 x 10
Overlap (%)	>90	>90
Incidence Angle (°)	20 - 70	
Convergence Angle (°)	15 - 30	
Spatial Resolution (m)	<0.75	

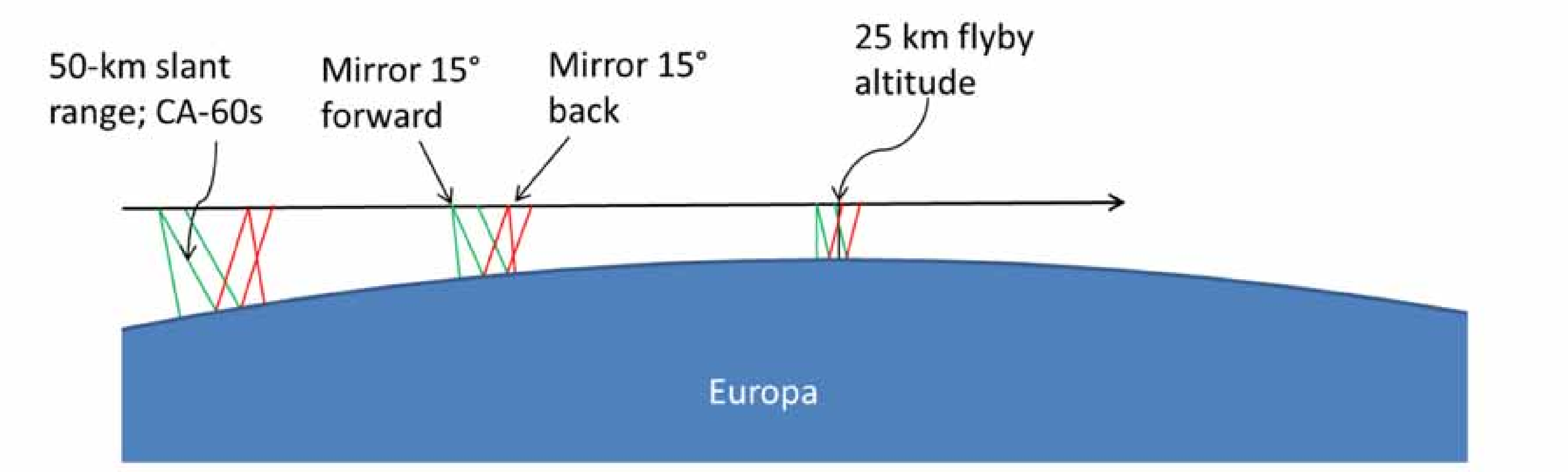
Reconnaissance Camera

Instrument Description

- Pushbroom panchromatic visible imager
- Single-axis along-track flip mirror
- IFOV of 10 µrad (ground sample dimension of 0.5 m/pixel from a range of 50 km)
- Cross-track FOV of 92 mrad (4.6-km swath width from 50 km range)

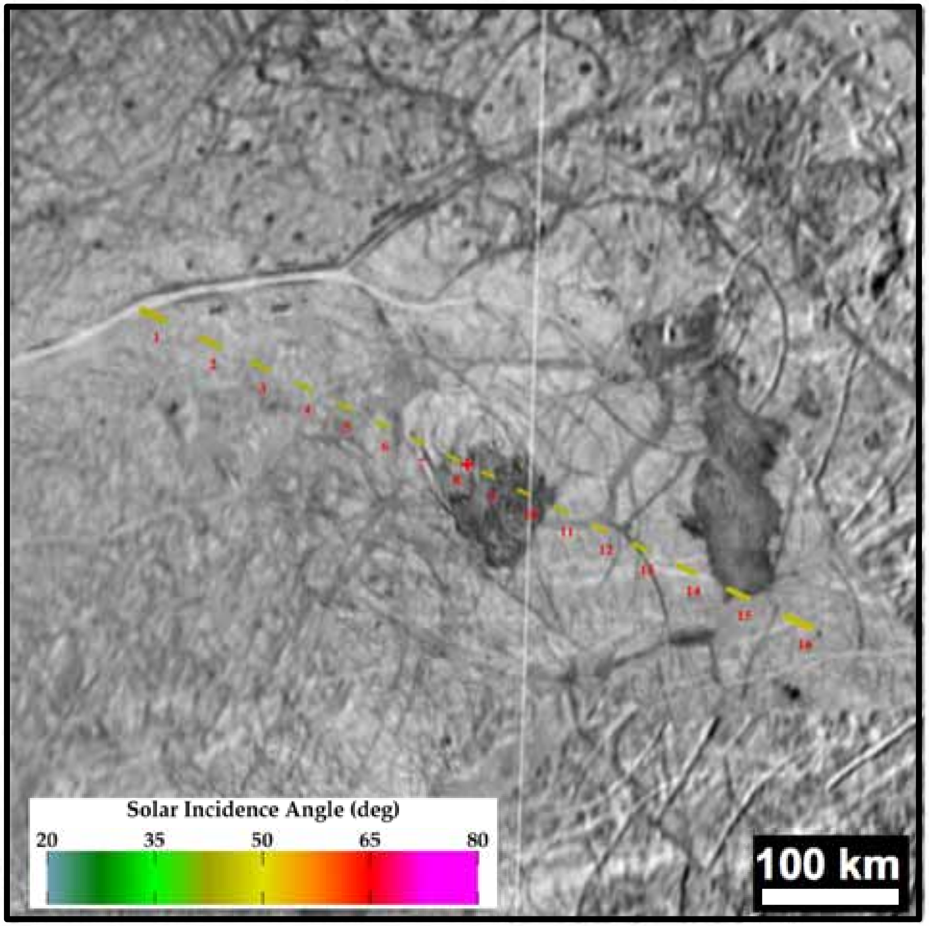
Observing Scenario

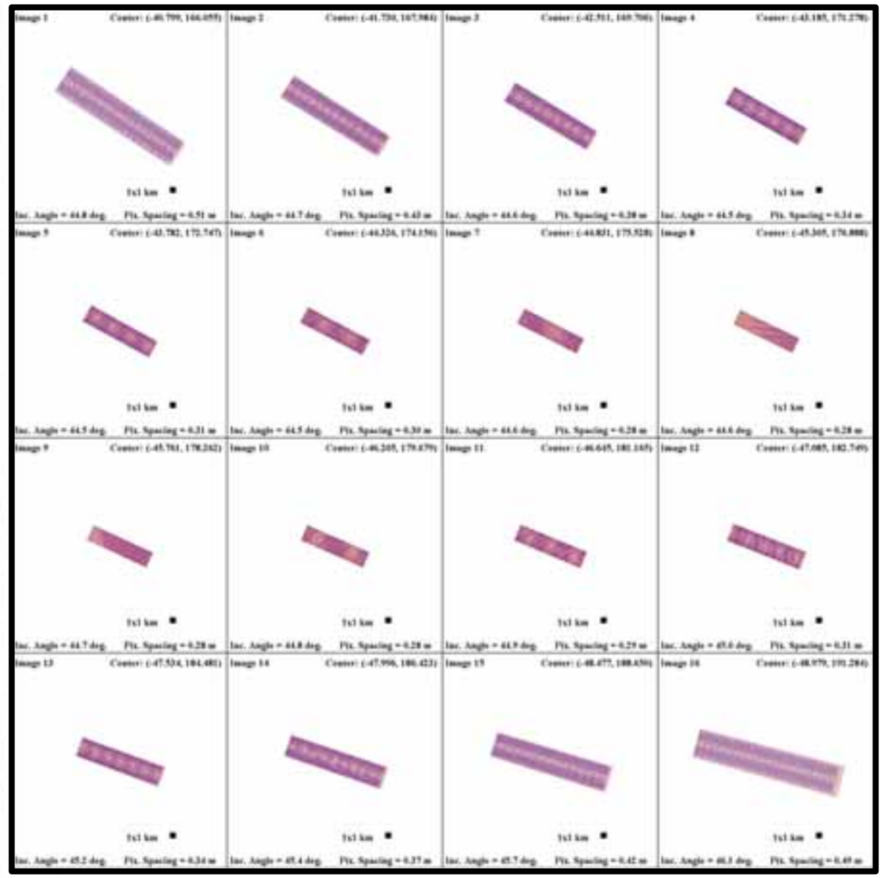
- Can meet resolution requirement inside CA ±60s (assuming a flyby speed of 4.5 km/s)
- Length of the ground track for this period would be ~534 km
- Time to acquire a stereo pair would be ~9s at 50-km range down to about ~6s at CA



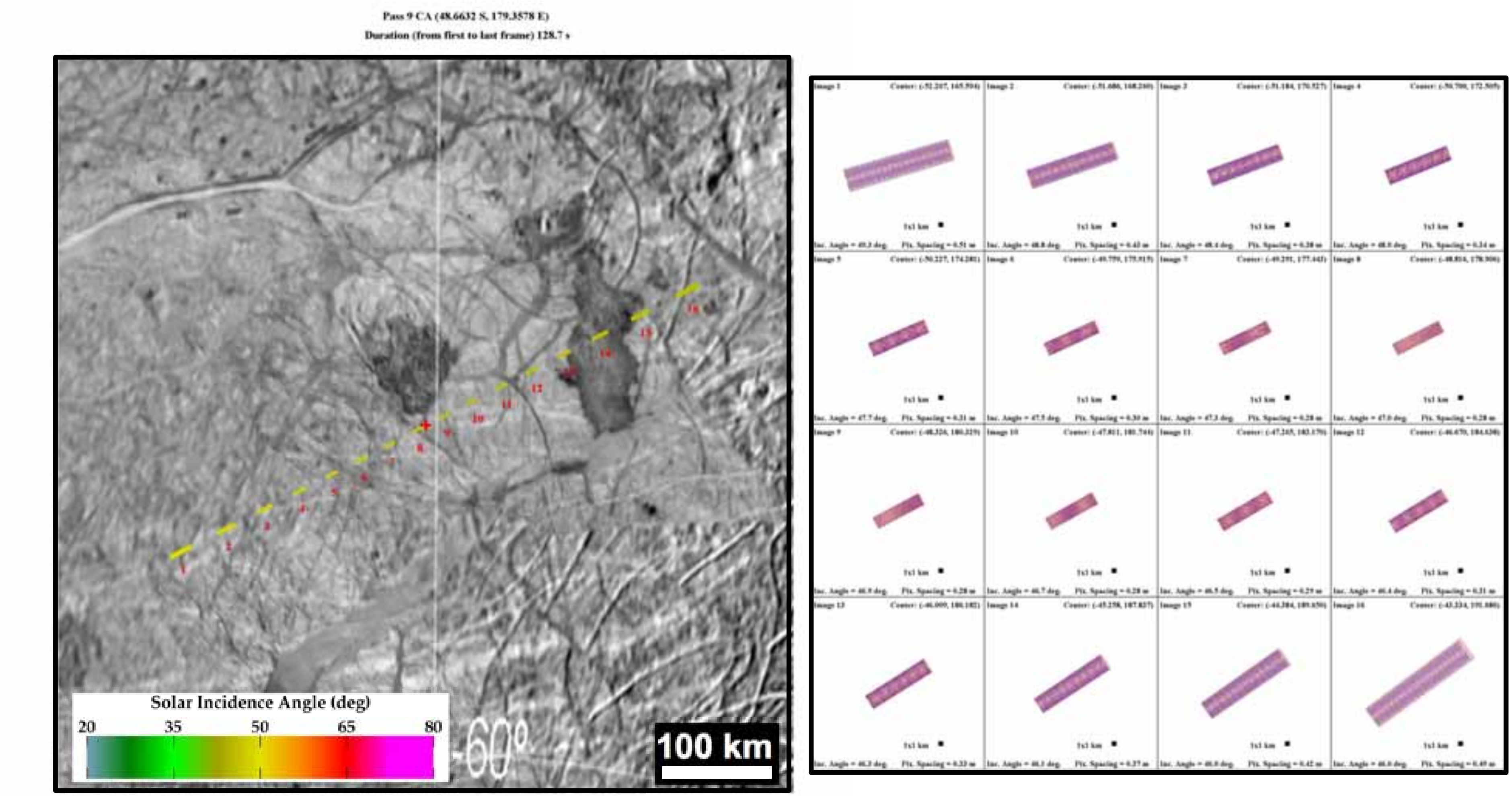
Reconnaissance Camera - Flyby 6

Pass 6 CA (45.4919 S, 177.4428 E)
Duration (from first to last frame) 129.8 s



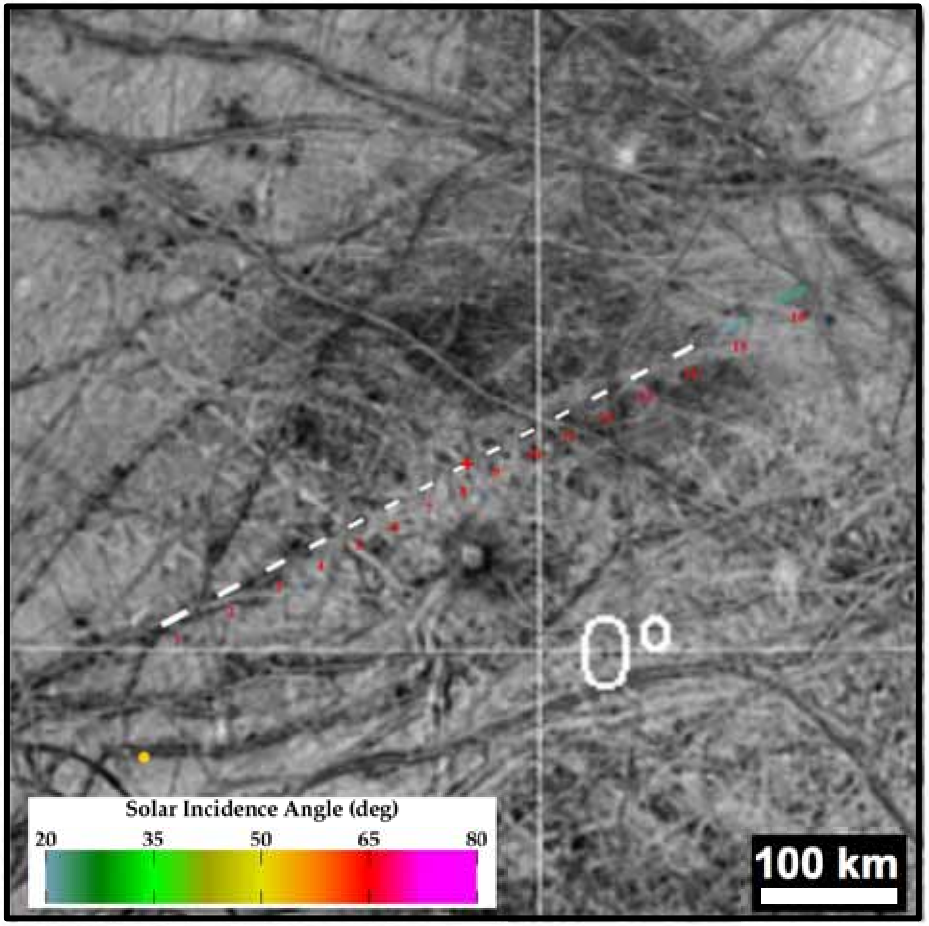


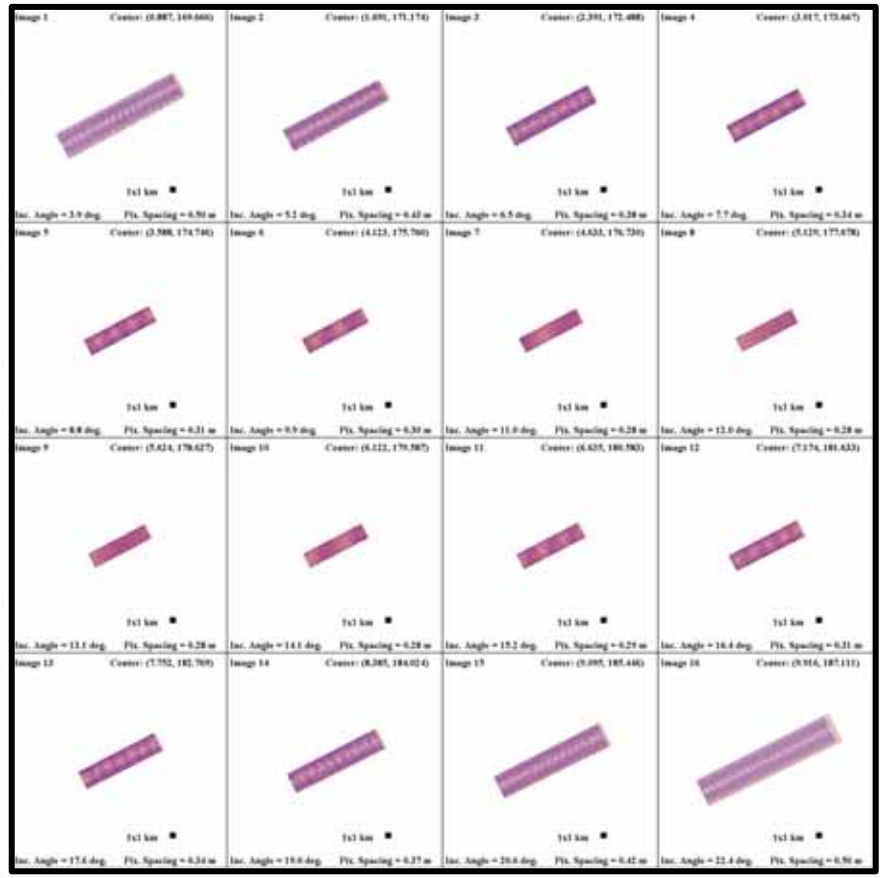
Reconnaissance Camera - Flyby 9



Reconnaissance Camera - Flyby 11

Pass 11 CA (5.2393 N, 177.8890 E)
Duration (from first to last frame) 129.0 s

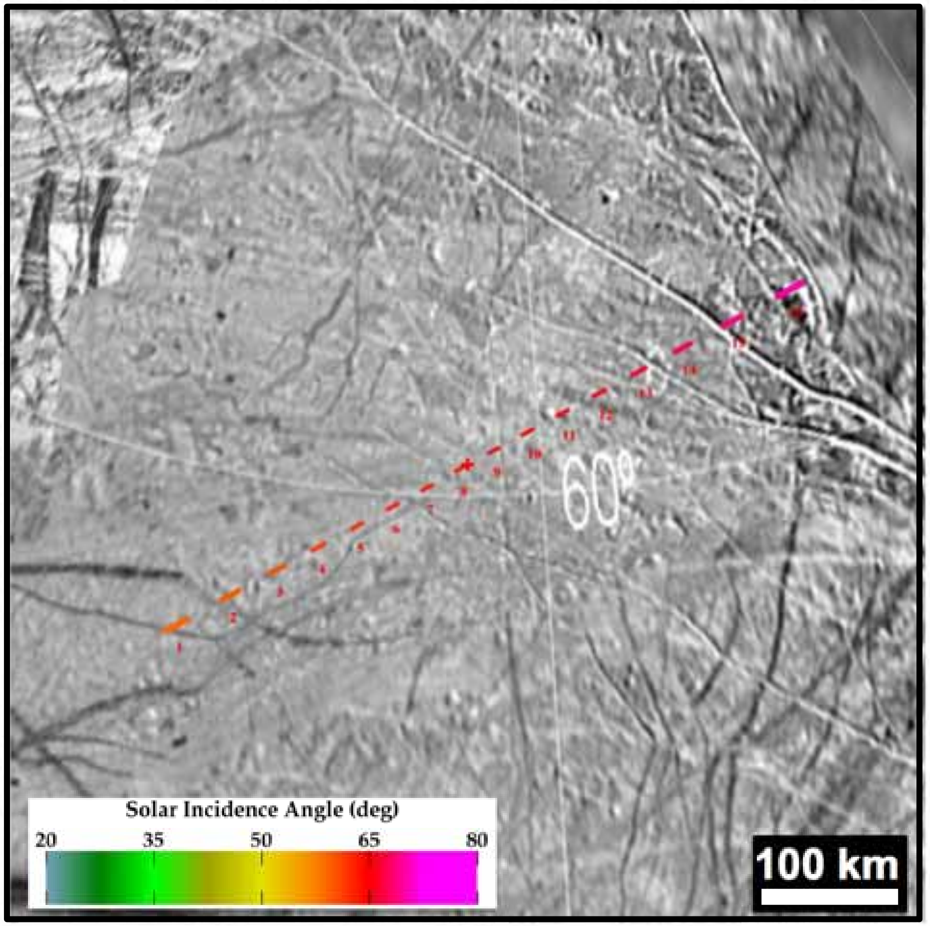


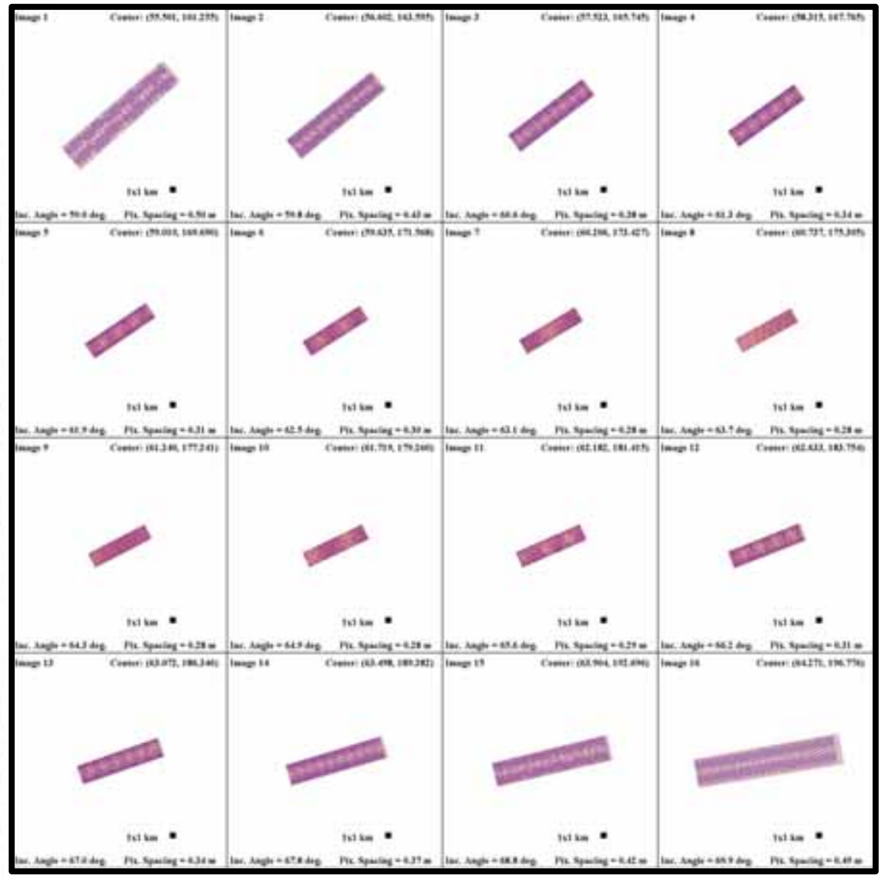


Reconnaissance Camera - Flyby 13

Pass 13 CA (60.8508 N, 175.7293 E)

Duration (from first to last frame) 128.7 s

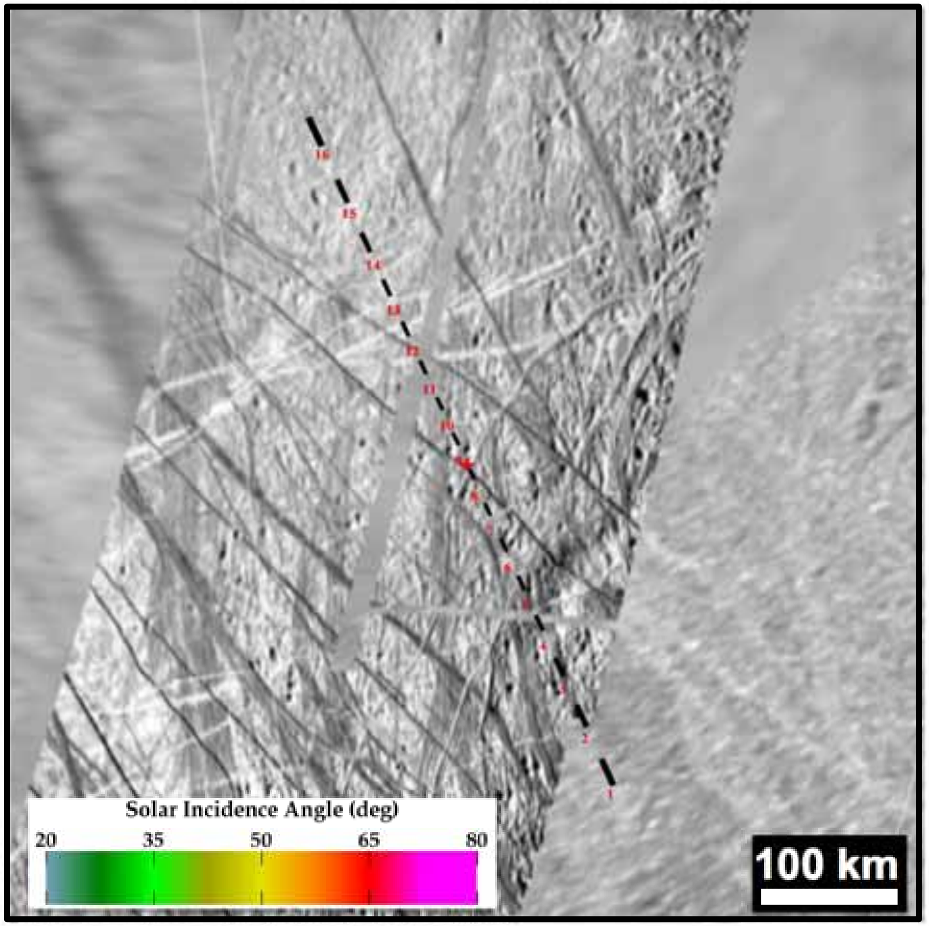


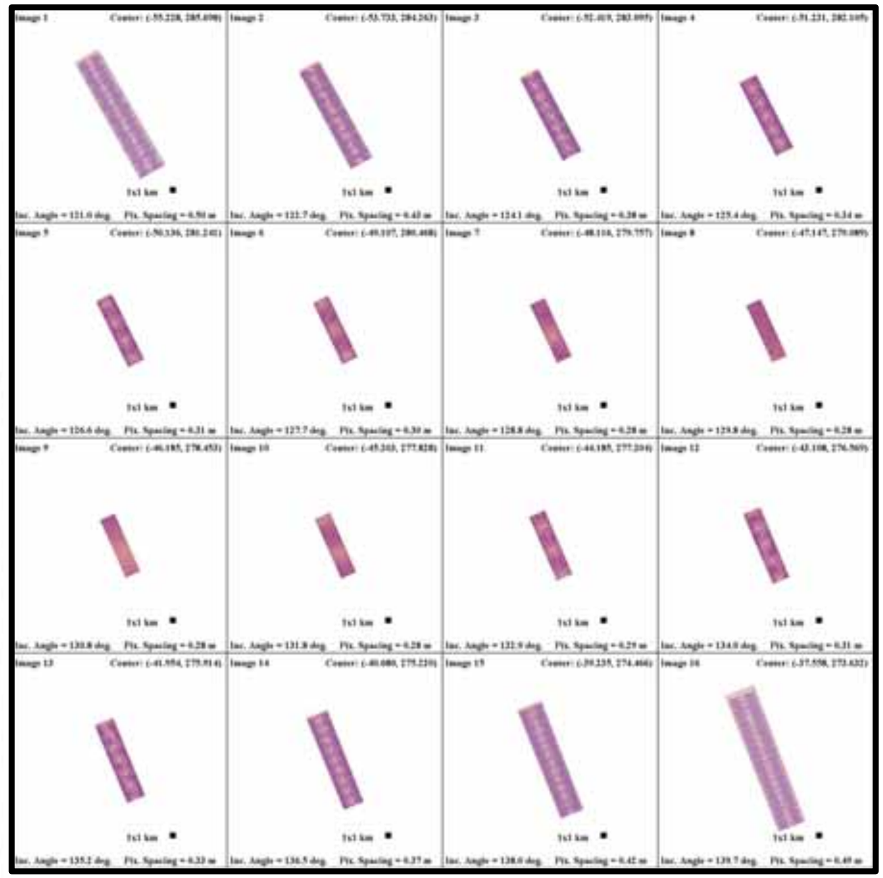


Reconnaissance Camera - Flyby 28

Pass 28 CA (46.8973 S, 81.0780 W)

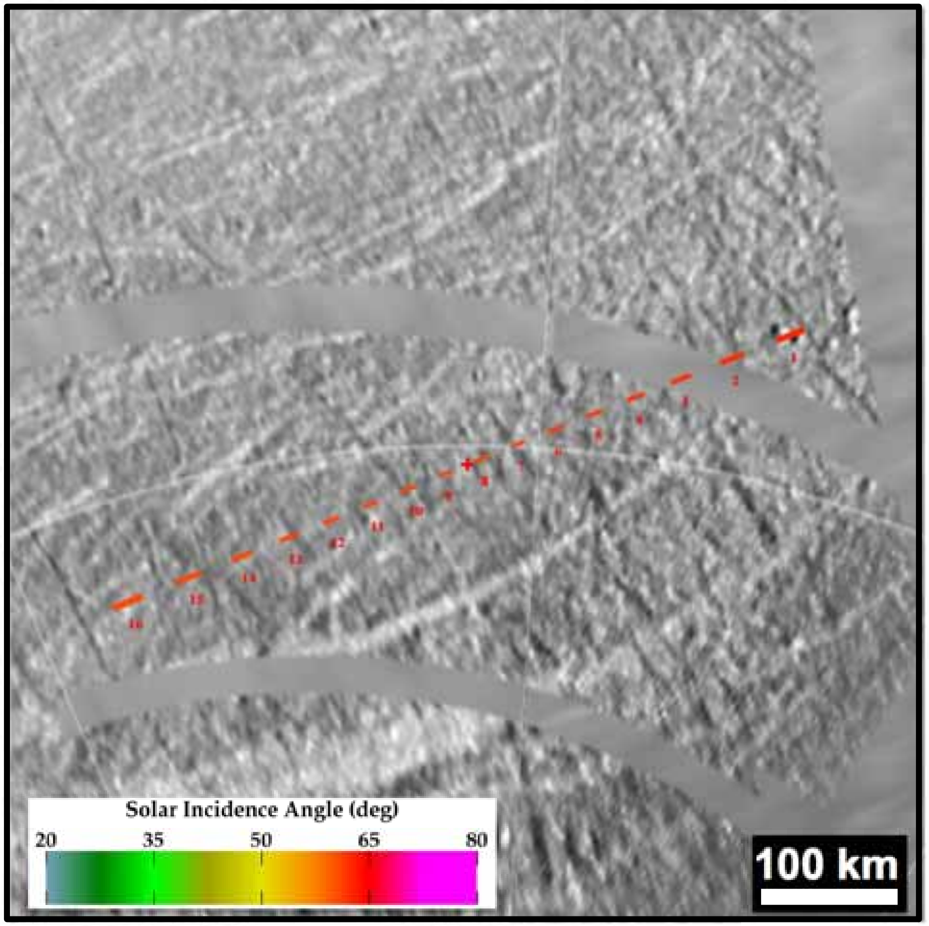
Duration (from first to last frame) 123.8 s

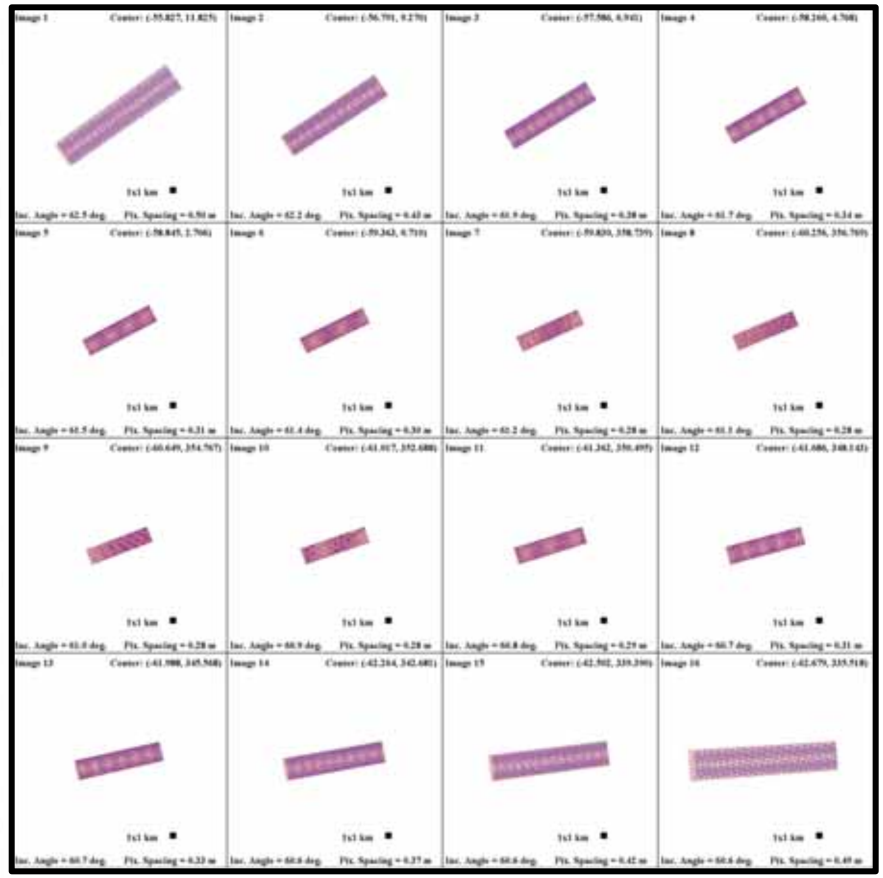




Reconnaissance Camera - Flyby 35

Pass 35 CA (60.4118 S, 3.9996 W)
Duration (from first to last frame) 127.8 s

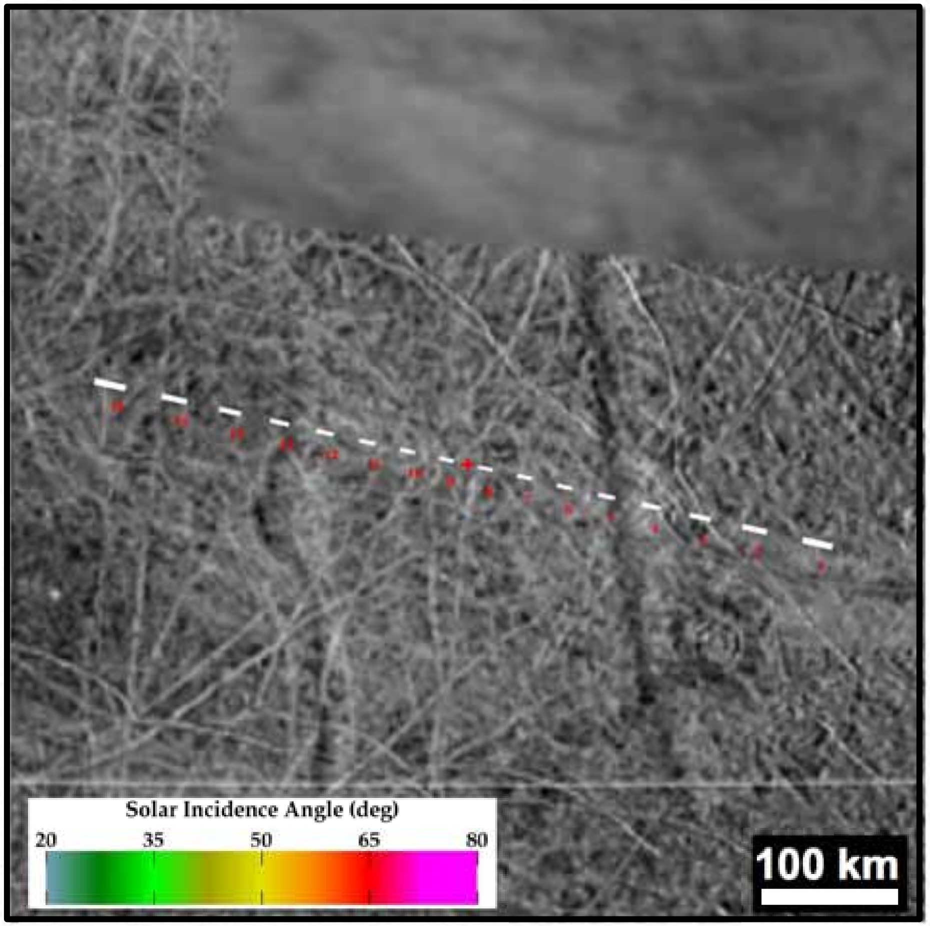


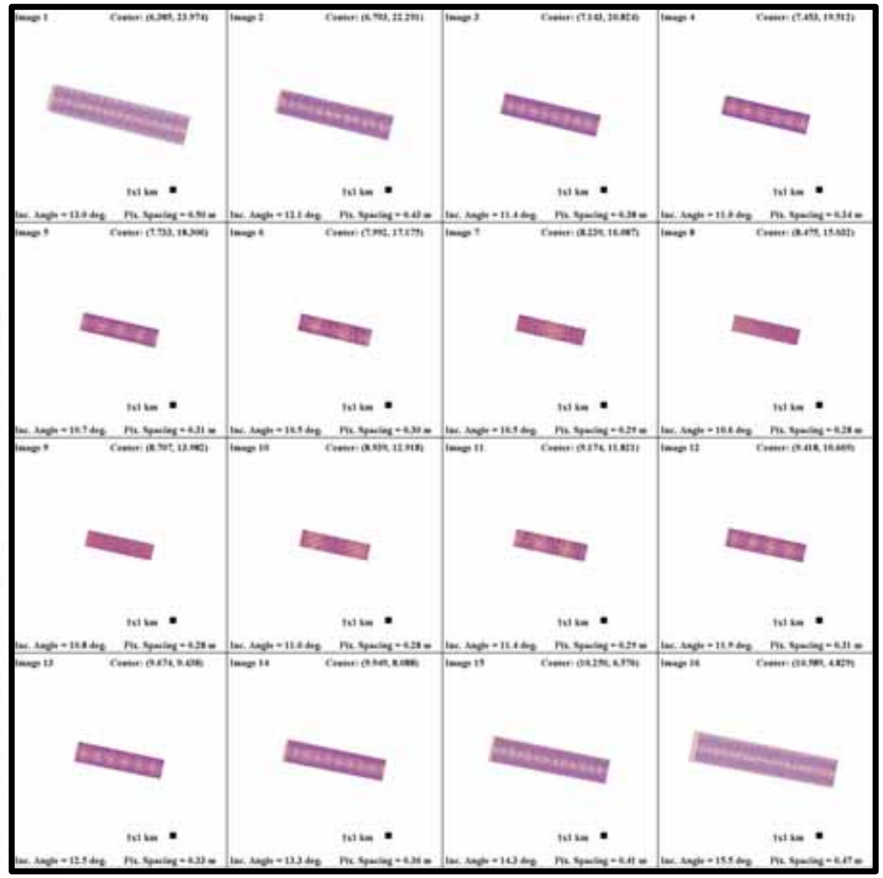


Reconnaissance Camera - Flyby 38

Pass 38 CA (8.5823 N, 14.5485 E)

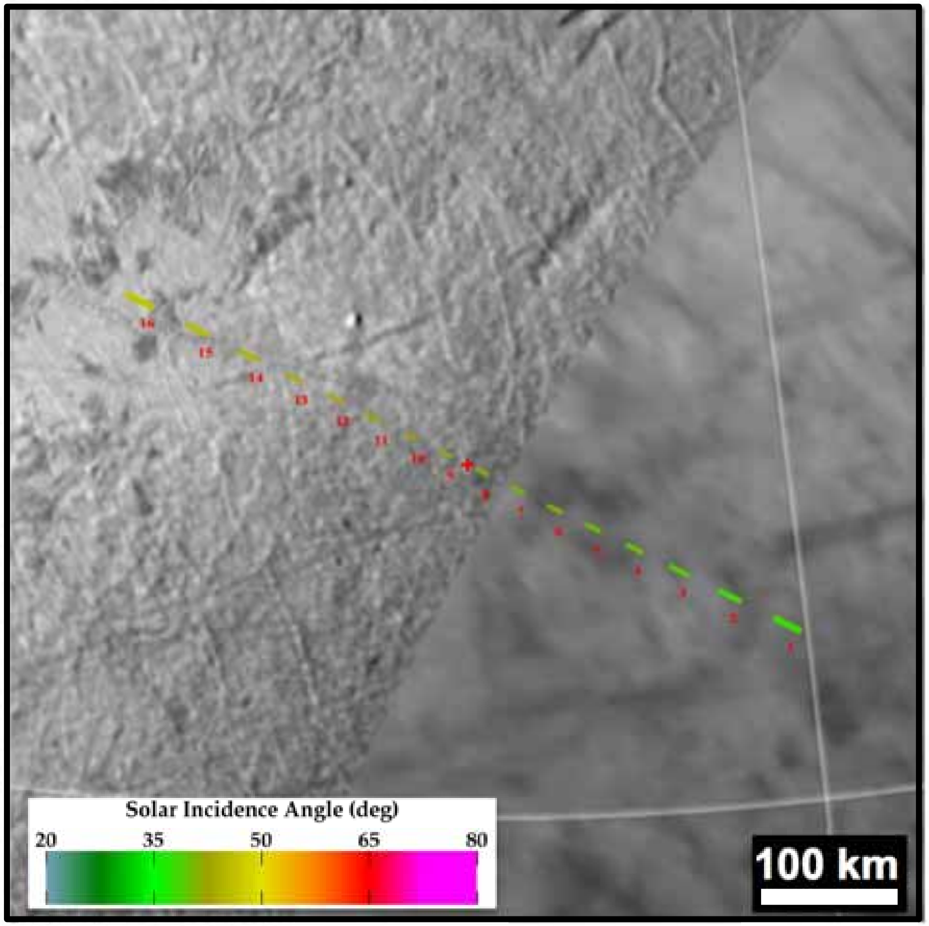
Duration (from first to last frame) 131.8 s

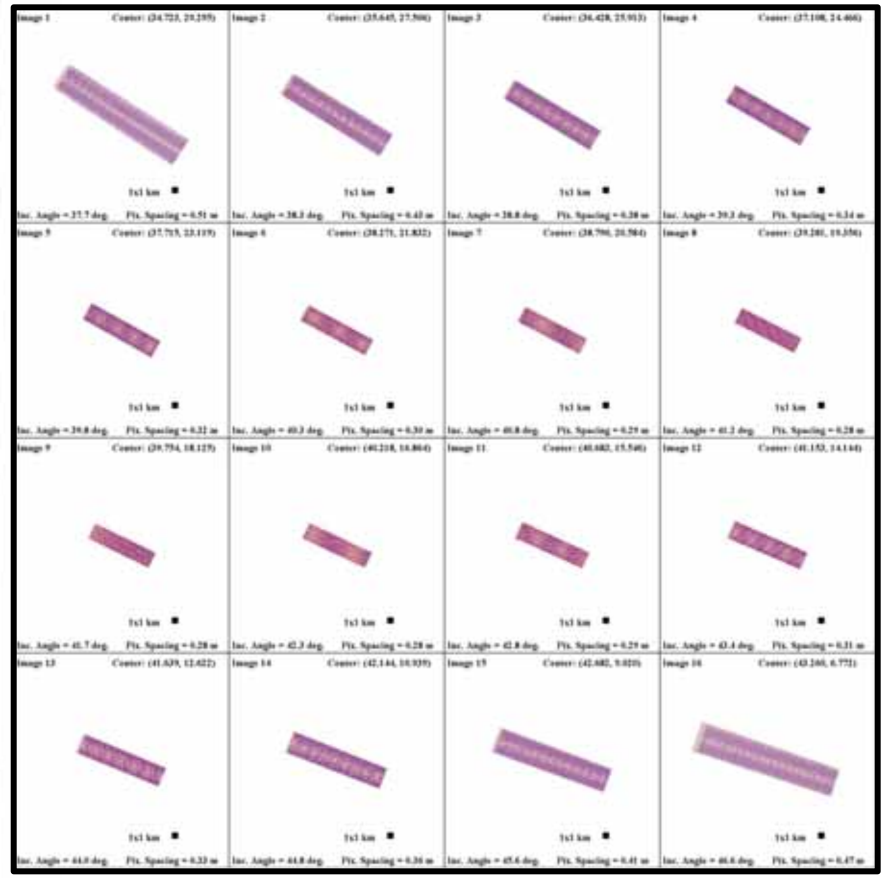




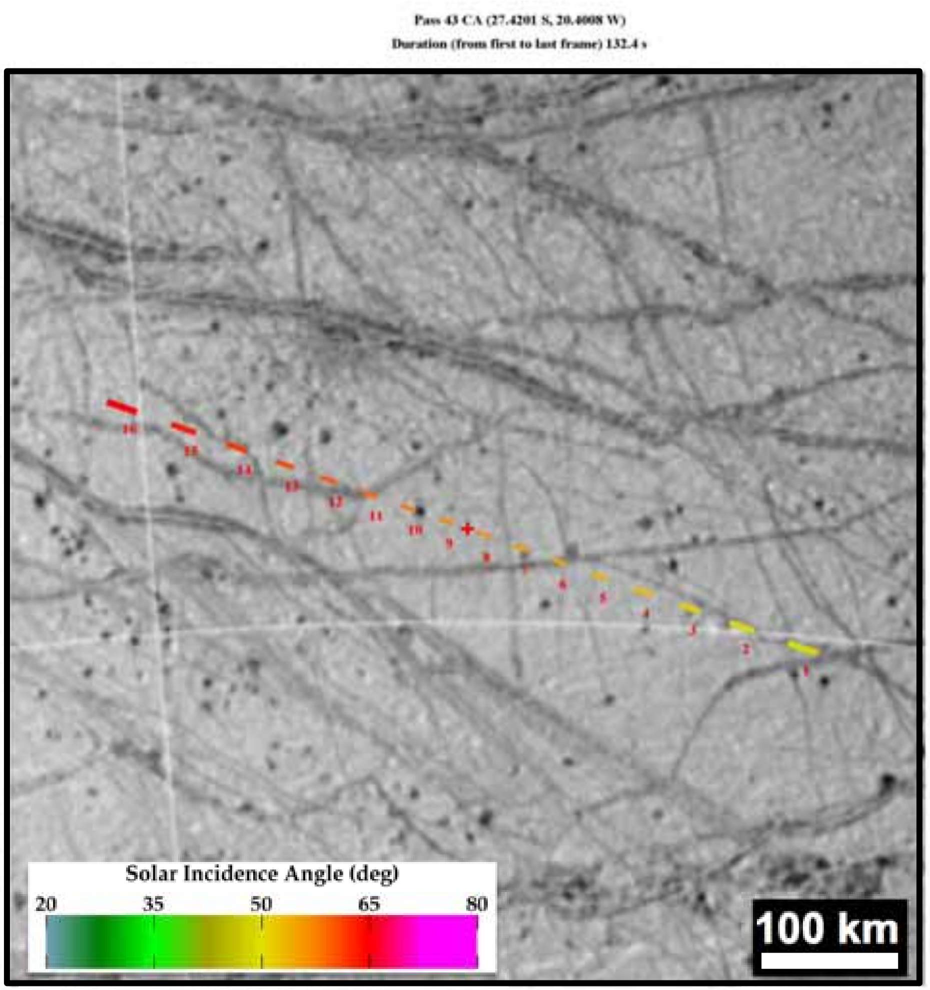
Reconnaissance Camera - Flyby 40

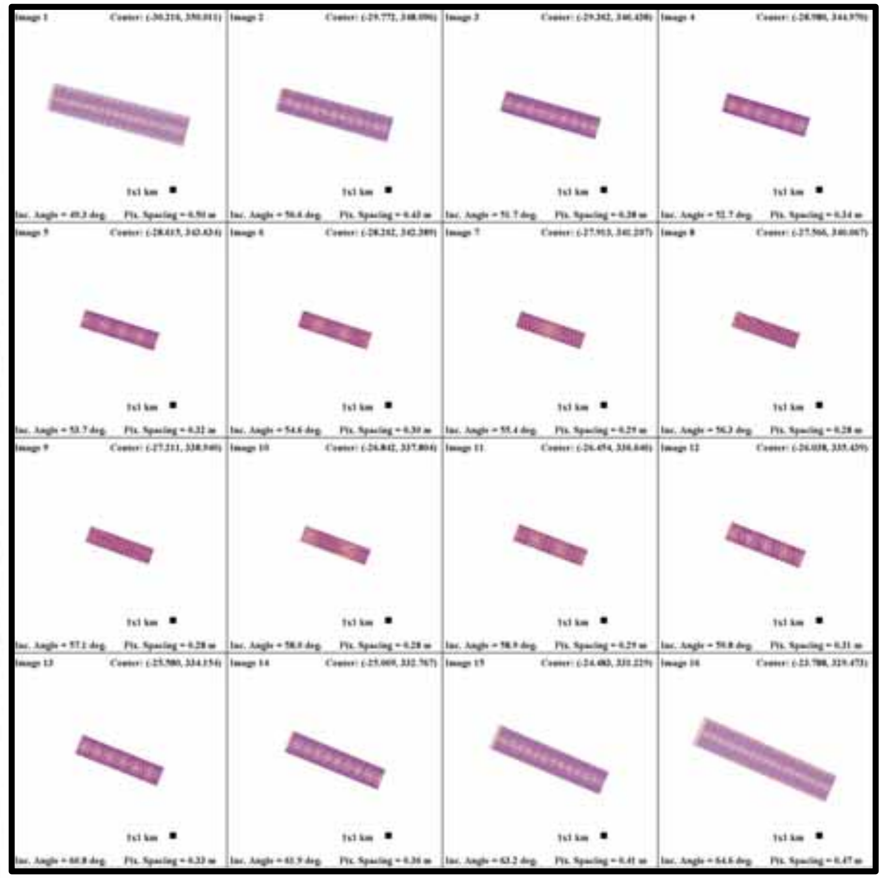
Pass 40 CA (39.4805 N, 18.8428 E)
Duration (from first to last frame) 131.9 s





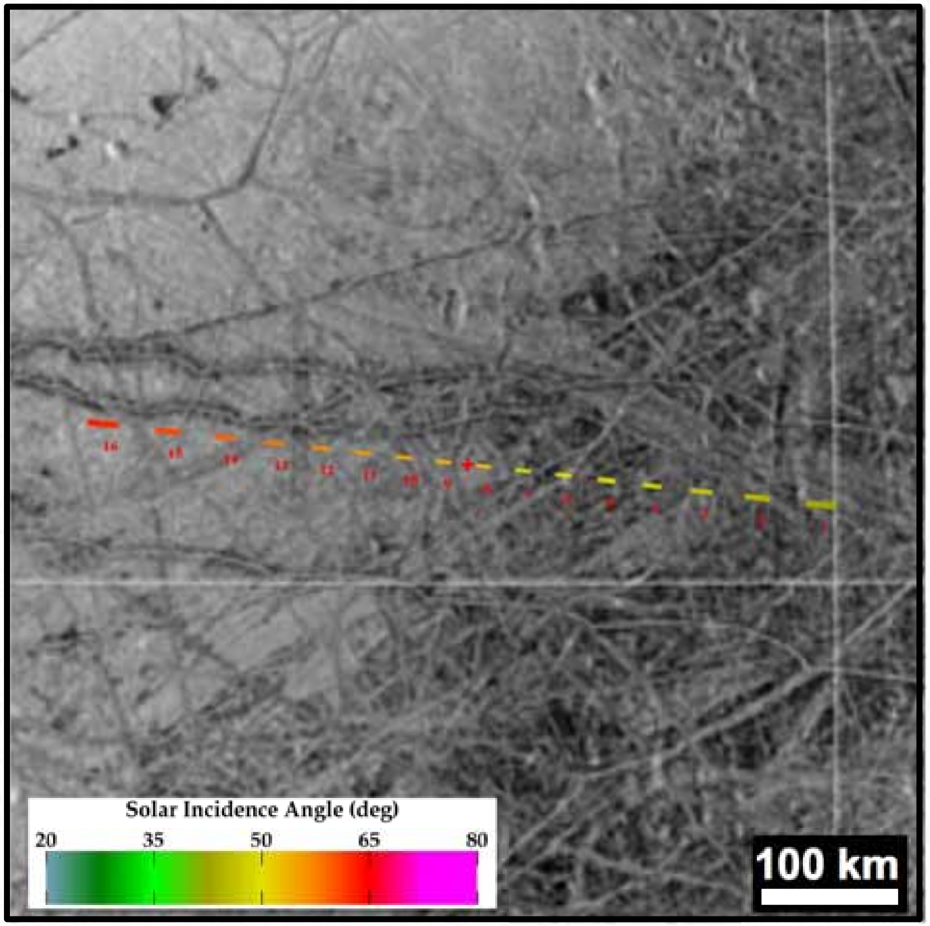
Reconnaissance Camera - Flyby 43

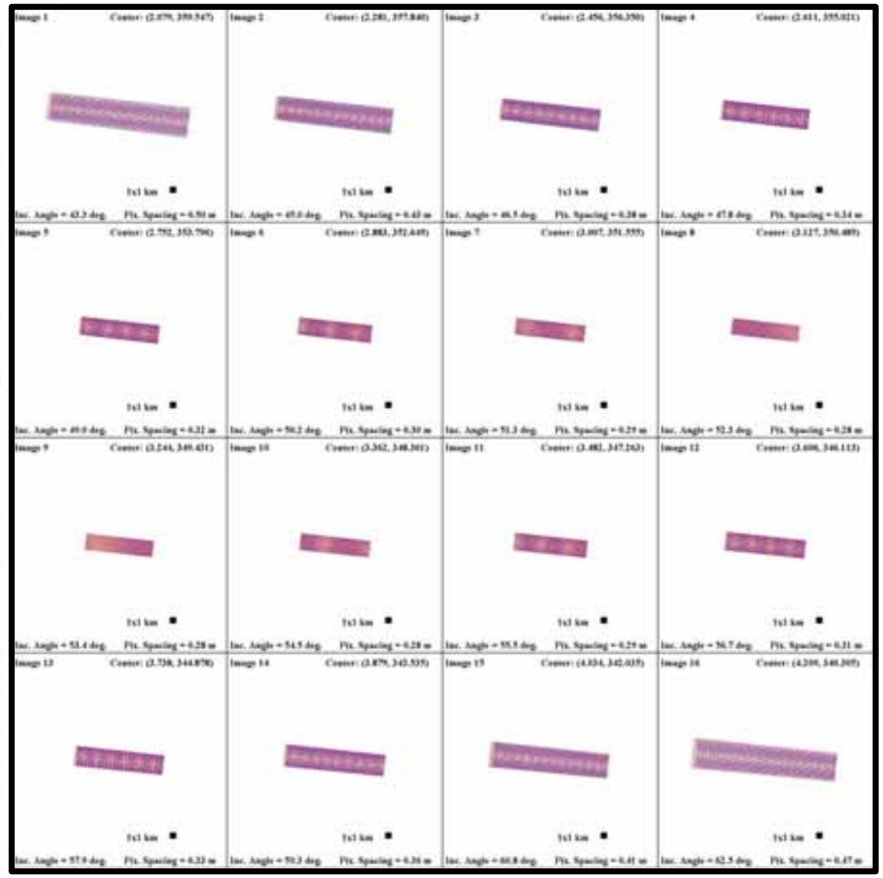




Reconnaissance Camera - Flyby 45

Pass 45 CA (3.1731 N, 9.9280 W)
Duration (from first to last frame) 134.3 s





Thermal Imager

<u>Measurements</u>

- SL.1b - Characterize the fractional area of block coverage and the areal distribution of roughness elements [R2].
- SL.3a - Determine the regolith-component thermal inertia of the upper decimeter-scale surface layer [R3].
- SL.4a - Characterize the depth of regolith to "bedrock/ice" [R3].
- SV.4a - Determine the presence of surface temperatures in excess of diurnal equilibrium indicative of active or recent extrusion, upwelling, or outgassing [R3].

<u>Requirements</u>

	Baseline	Floor
Areal Coverage (km)	5 x 10	2 x 10
Local solar time (hr)	10am – 3pm *& 3am – 6am	
Spatial Resolution (m)	≤250 *≤15000	
Spectral Range	2 channels (<80% overlap)	

*requirement for SL.4a only

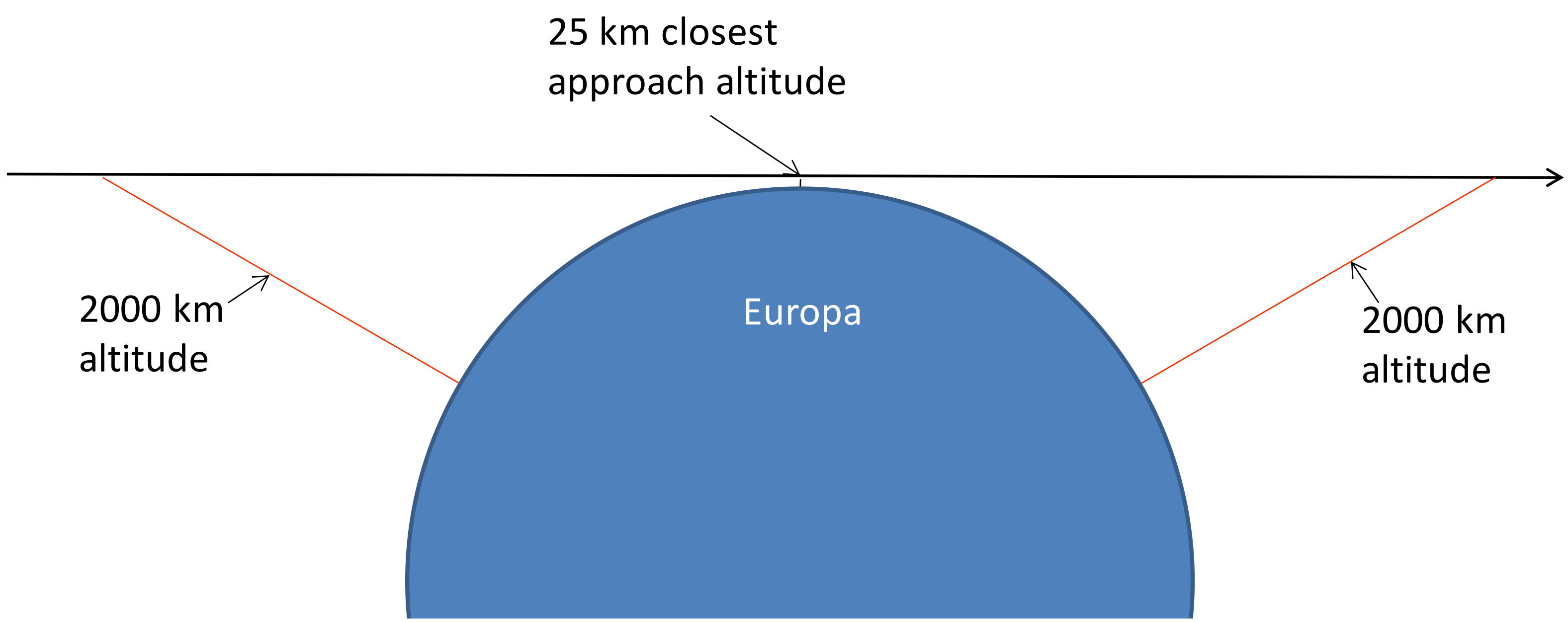
Thermal Imager

Instrument Description

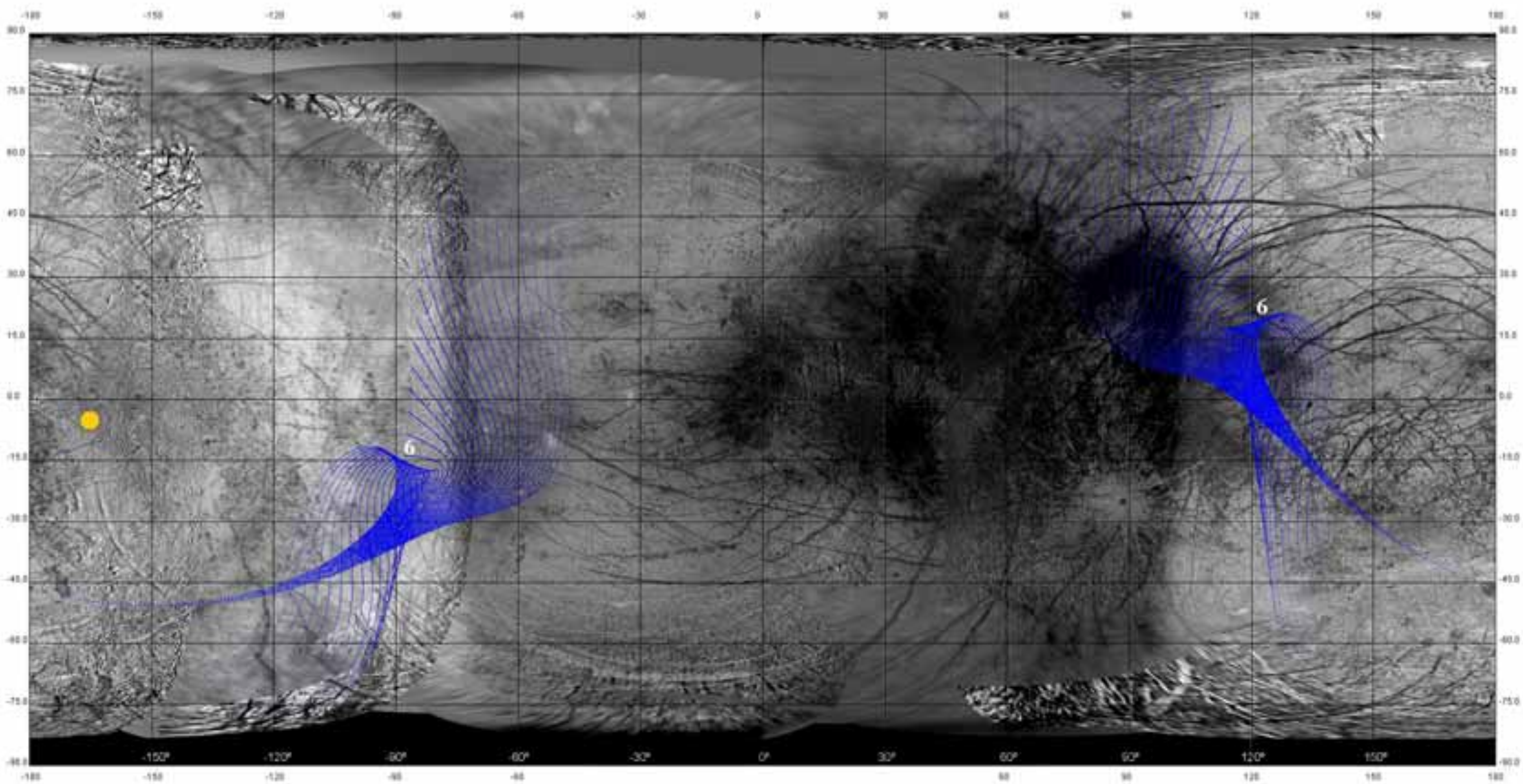
- Pushbroom infrared imager with two non-overlapping spectral channels (8 – 35 μm and 35 – 100 μm) plus a bolometric albedo measurement
- IFOV of 2.5 mrad
- Cross-track FOV of 100 mrad

Observing Scenario

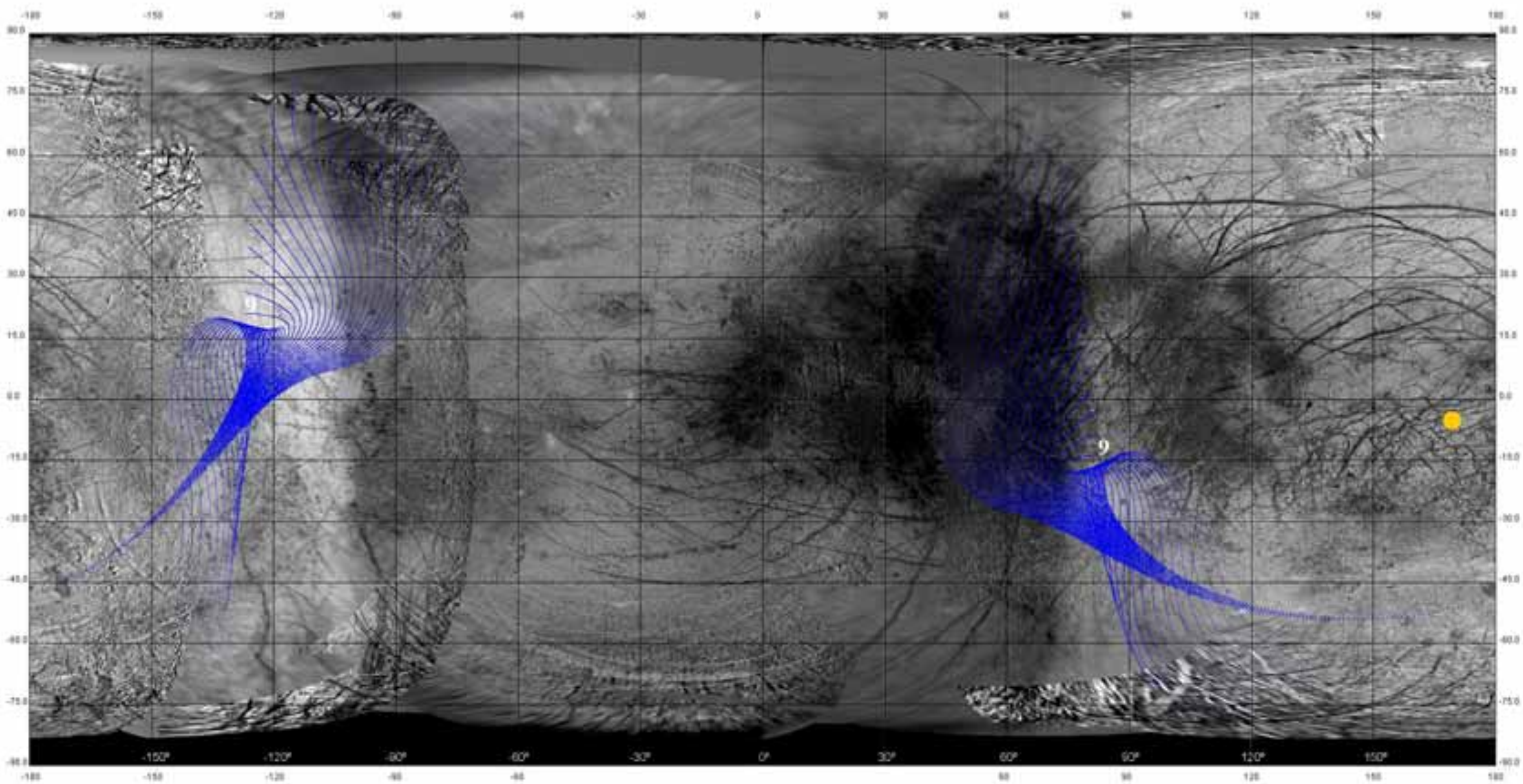
- Operate continuously below an altitude of ≤60,000 km
- Nominally nadir pointed and operated in pushbroom mode



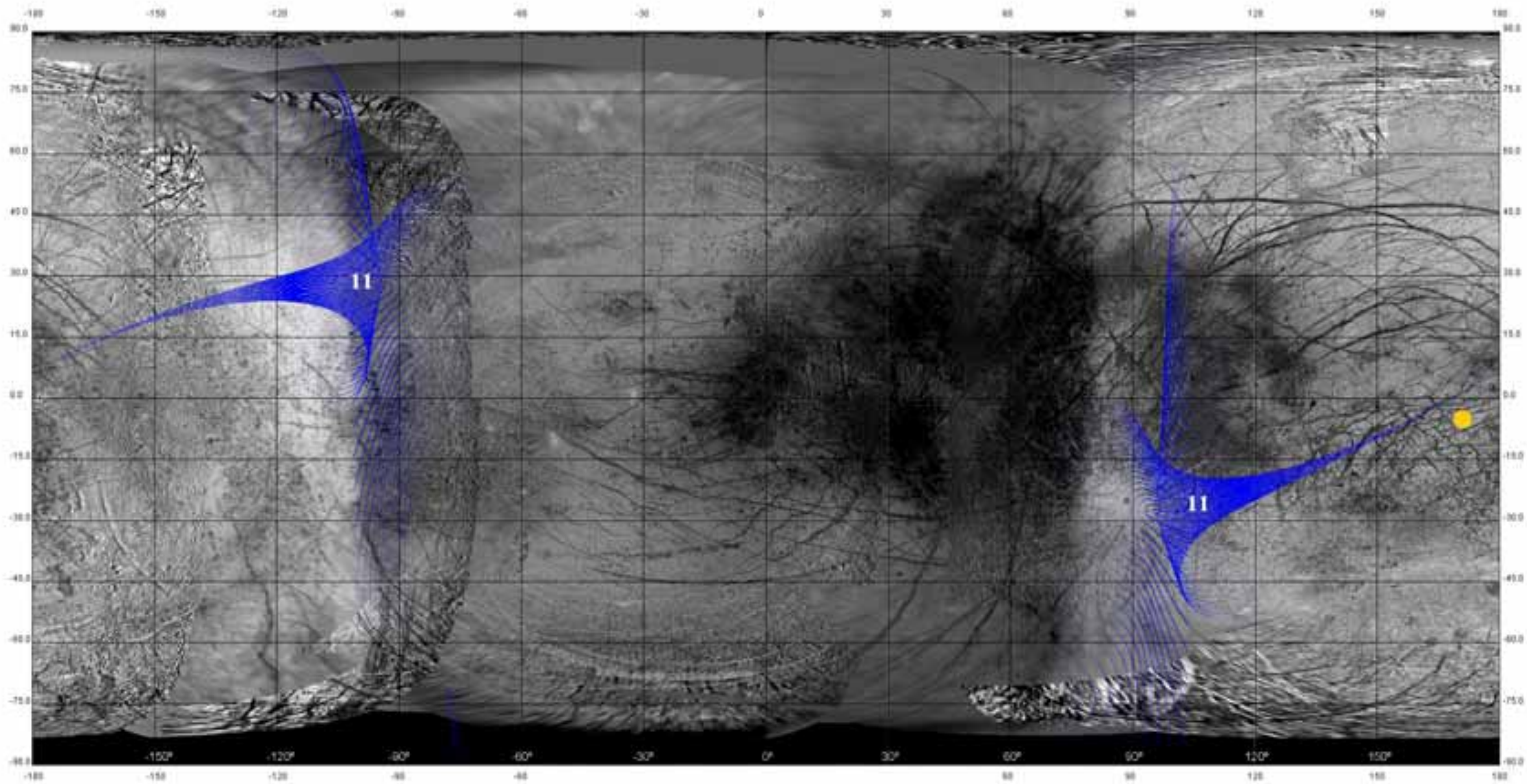
Thermal Imager – Flyby 6



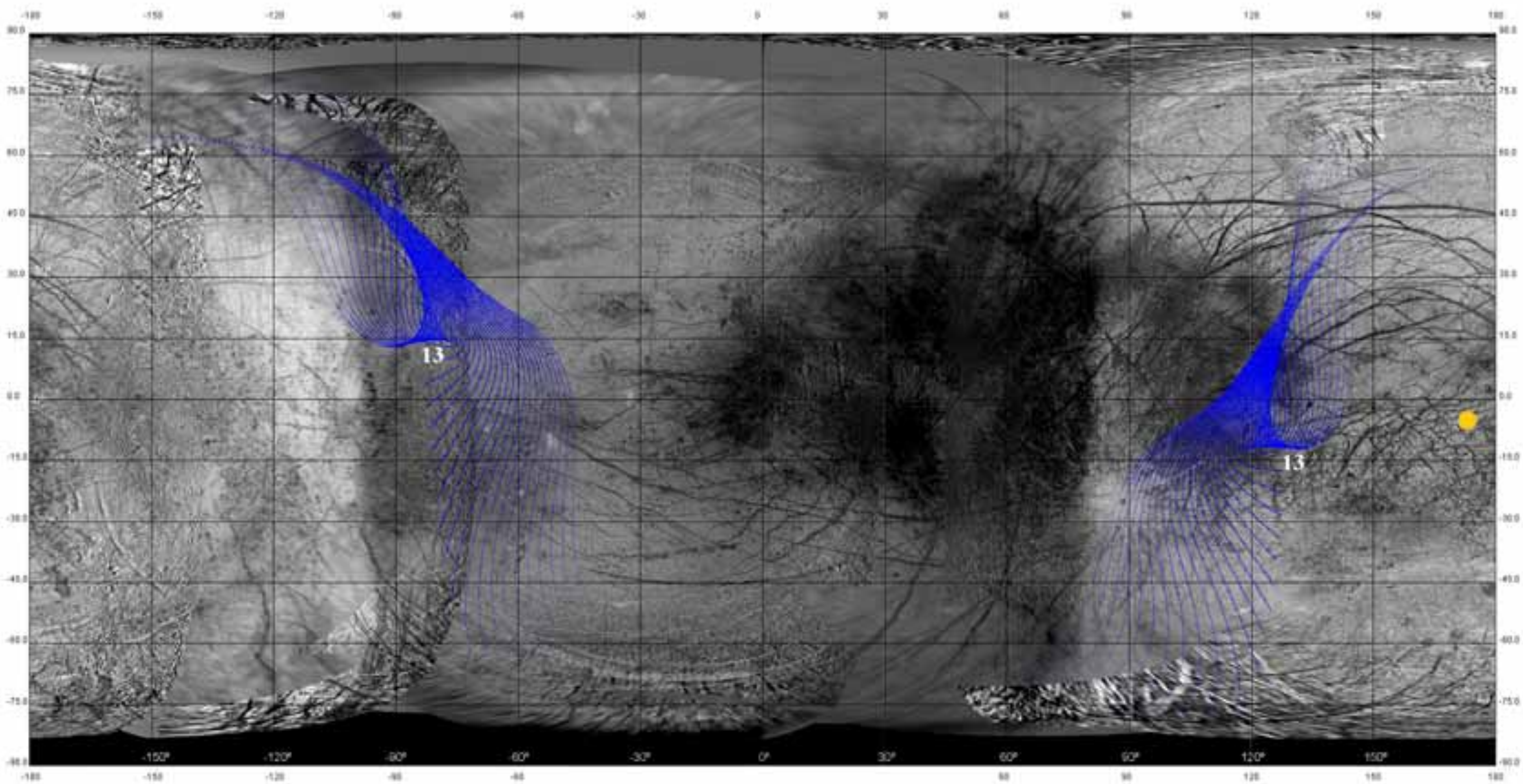
Thermal Imager – Flyby 9



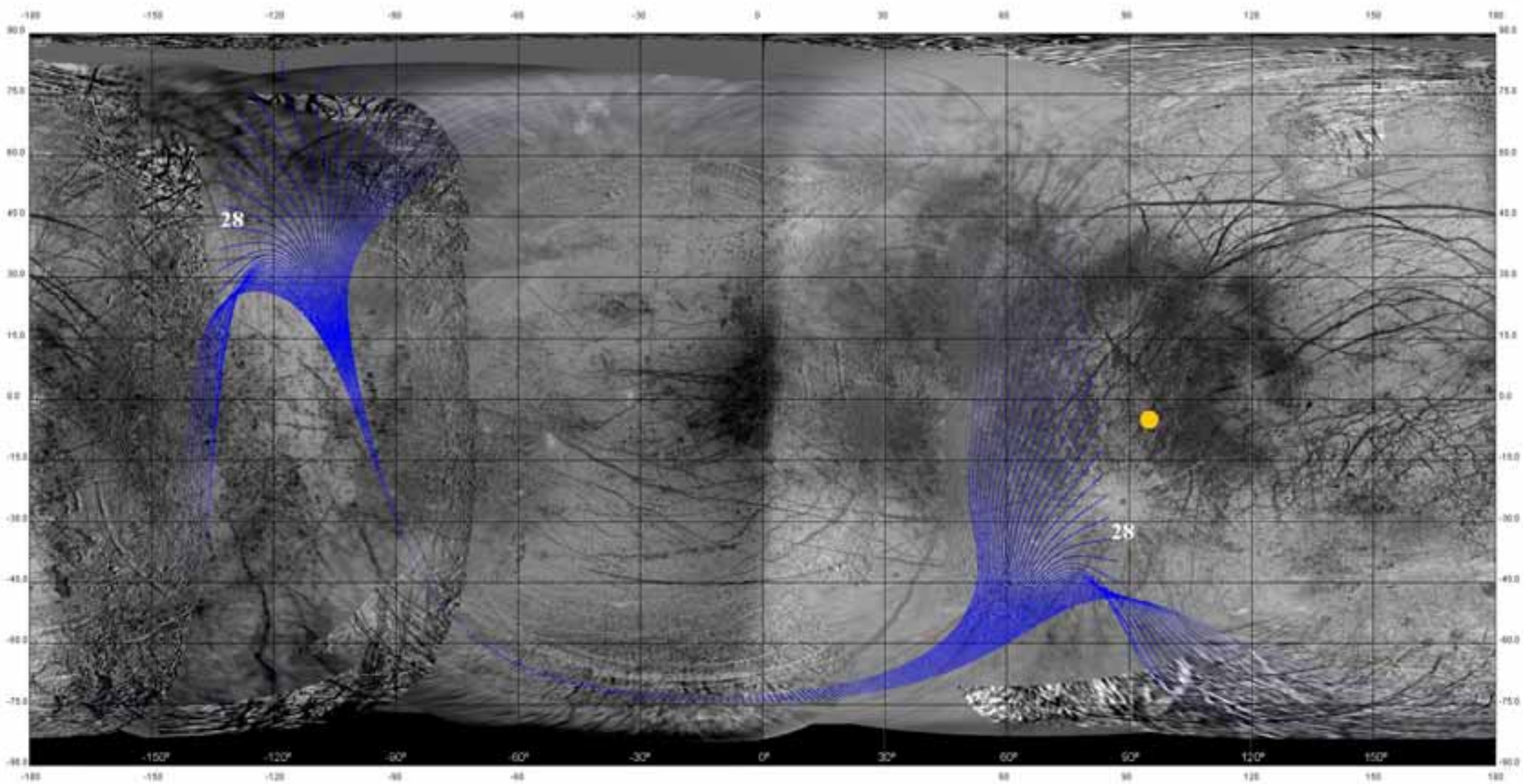
Thermal Imager – Flyby 11



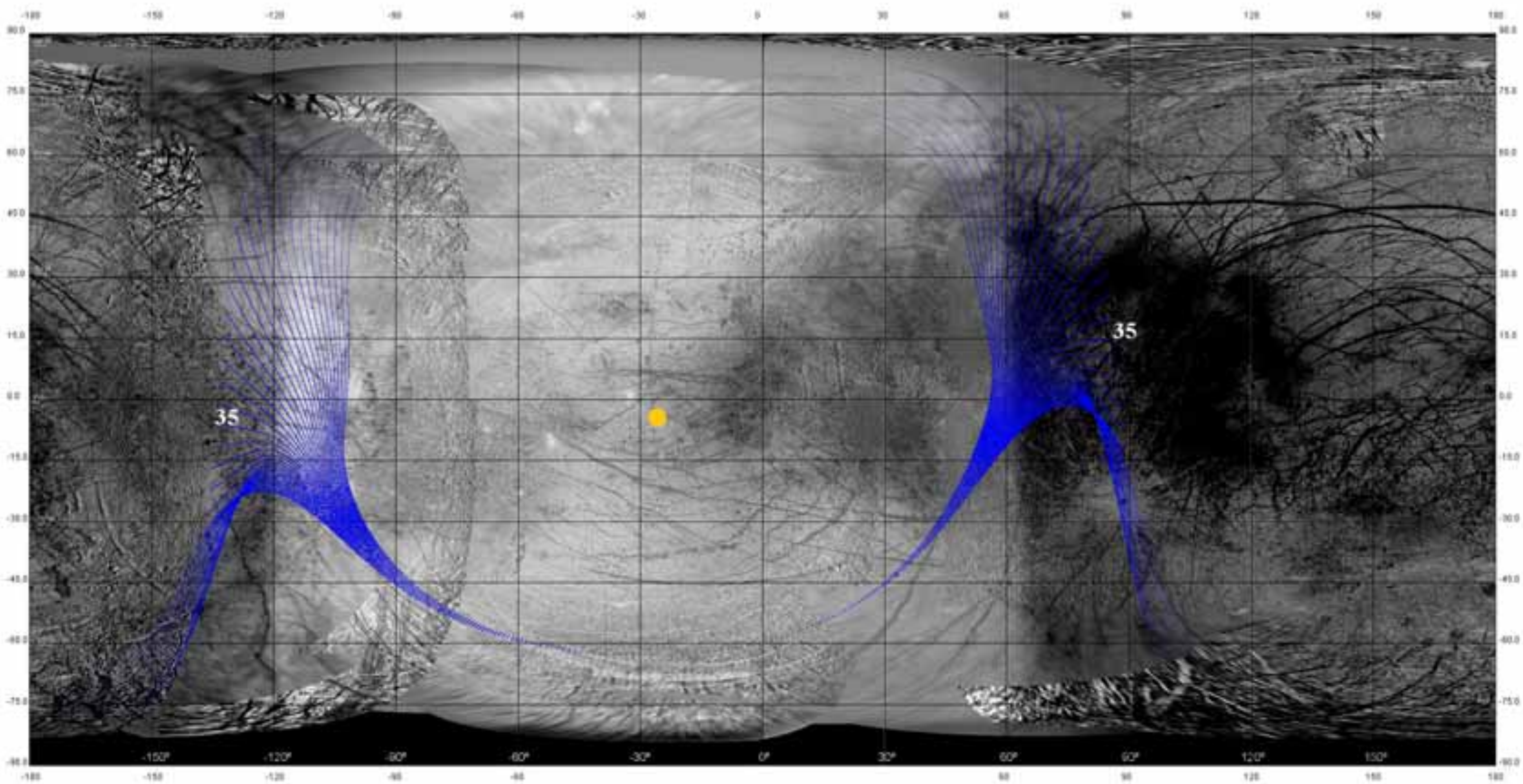
Thermal Imager – Flyby 13



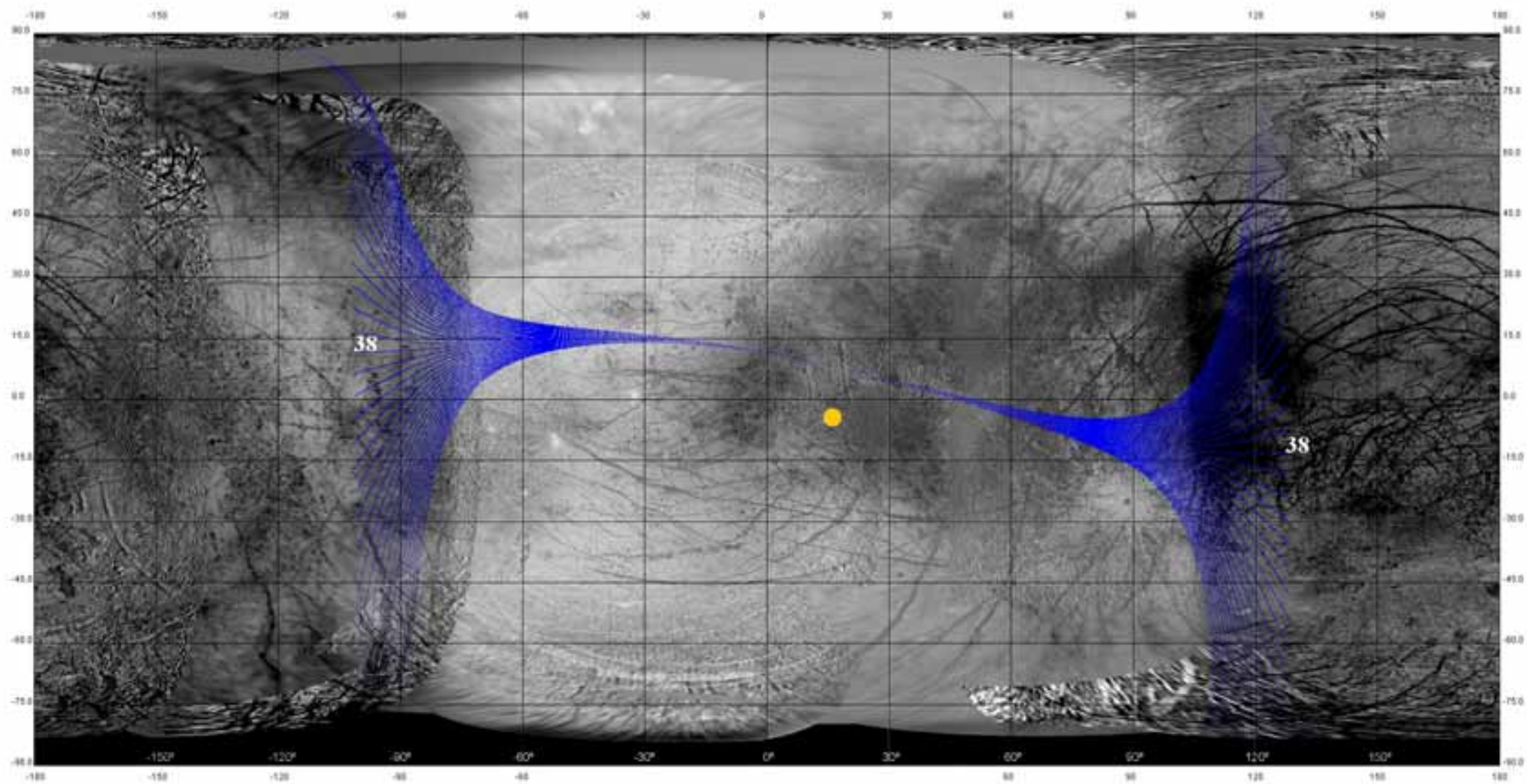
Thermal Imager – Flyby 28



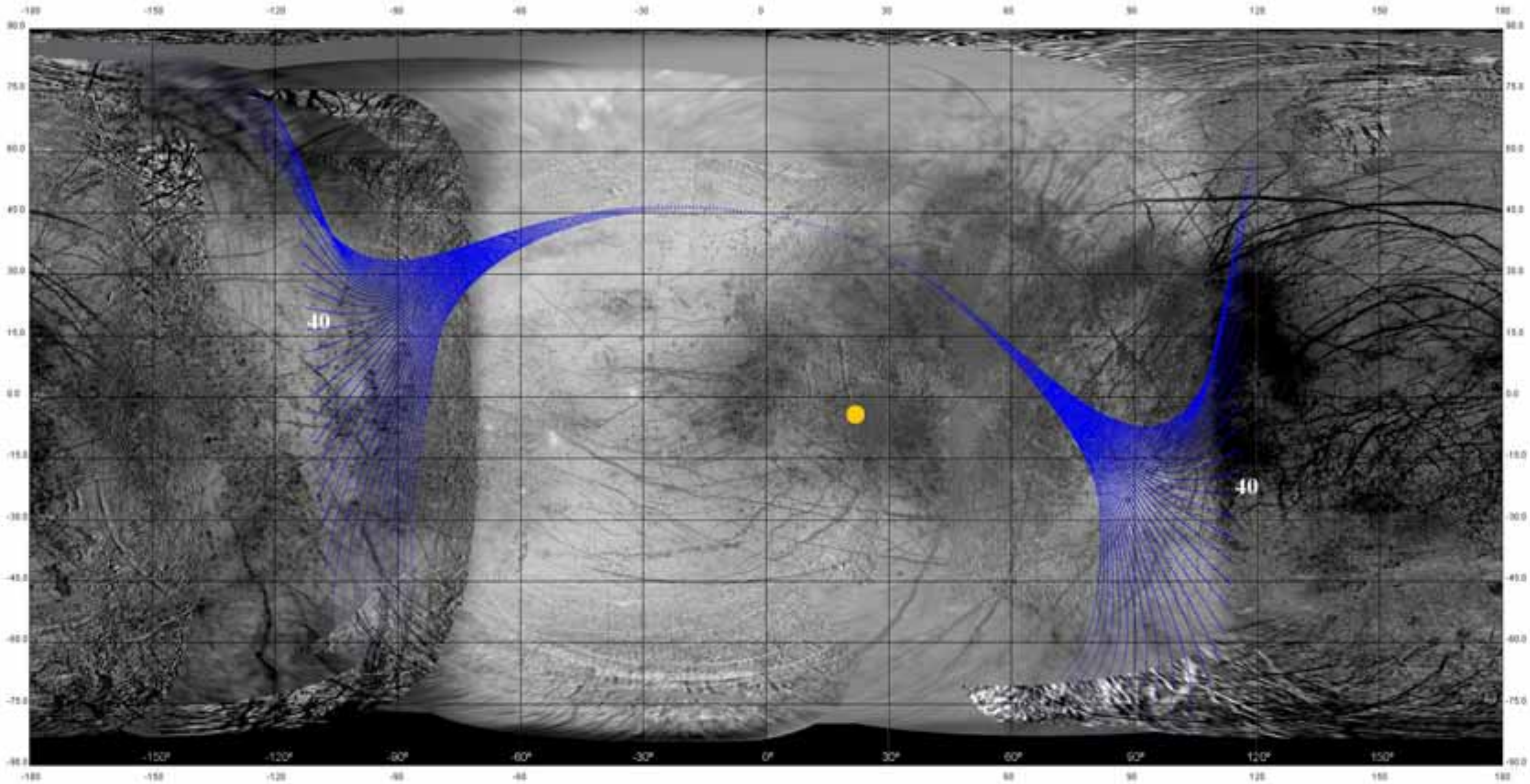
Thermal Imager – Flyby 35



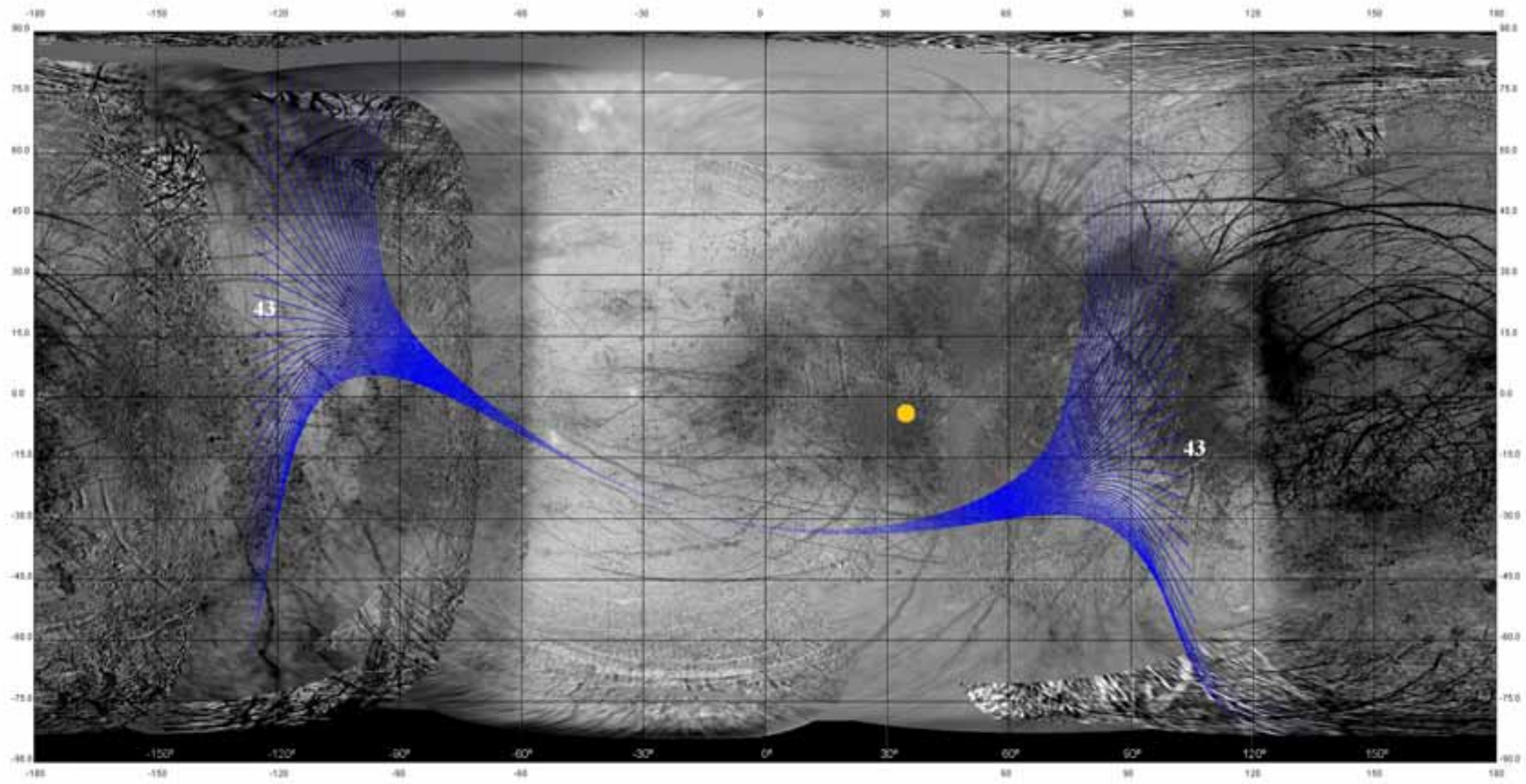
Thermal Imager – Flyby 38



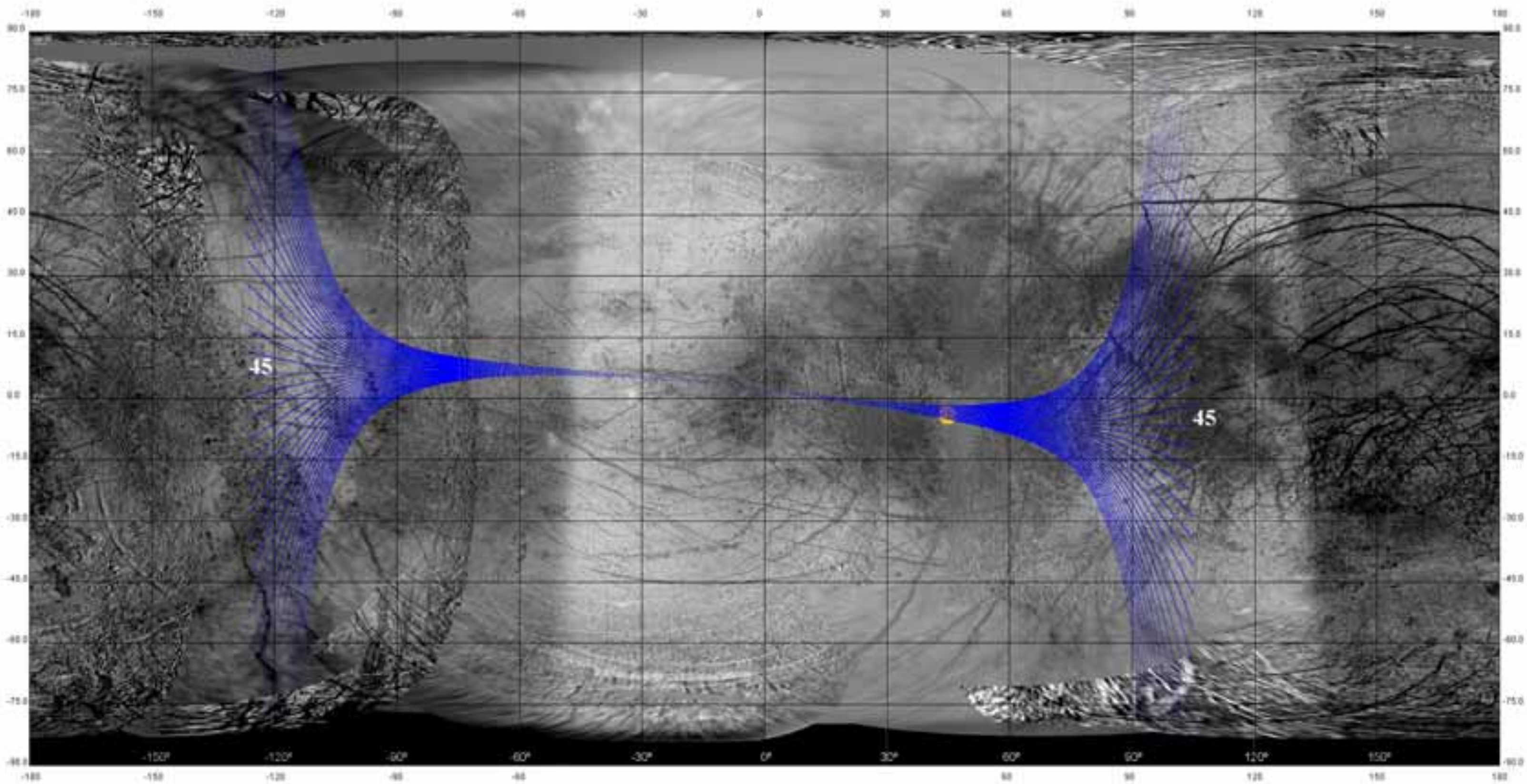
Thermal Imager – Flyby 40



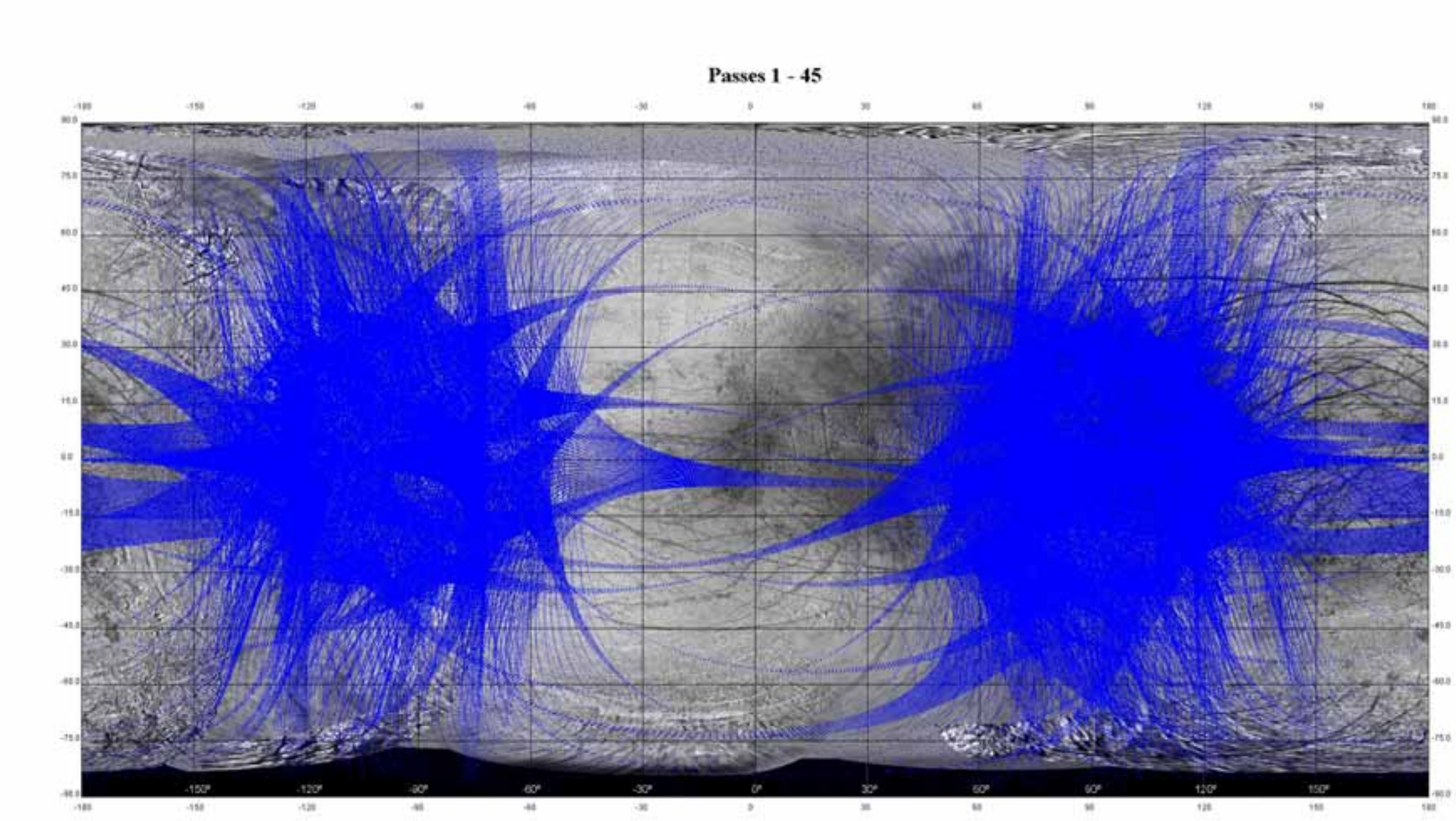
Thermal Imager – Flyby 43



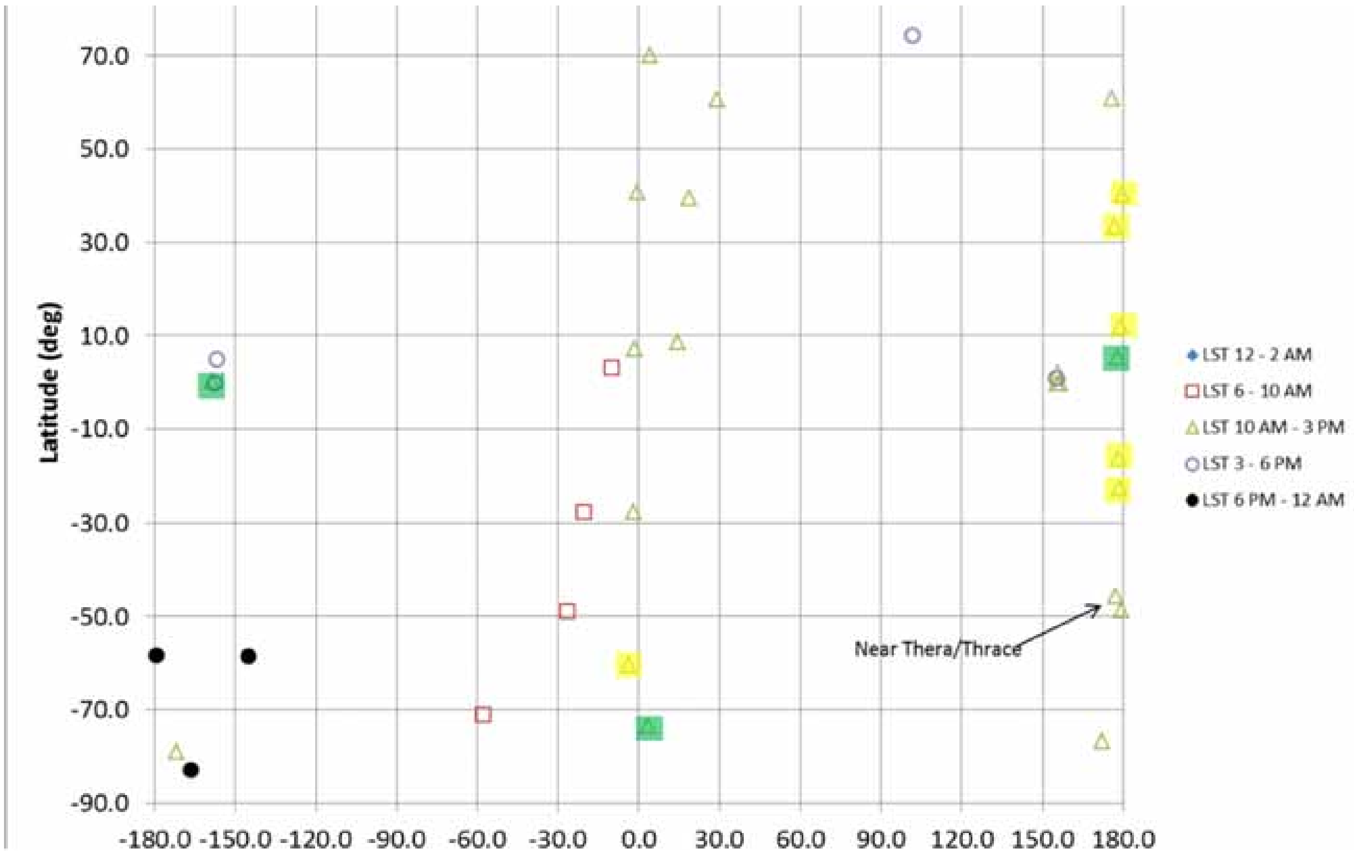
Thermal Imager – Flyby 45



Thermal Imager – All 45 Flybys



Thermal imaging on 13-F7 flyby



- Plot shows locations of 13-F7 flyby points with <103 km ca.
- The 6 sites that meet the RTM measurements only with off-nadir pointing are in light yellow; those that meet the requirements with strictly nadir pointing are in light green.
- Only two flybys (28 and 30) allow lower resolution pre-dawn viewing of sites observed earlier at midday.

Shortwave Infrared Spectrometer (SWIRS)

Measurements

- SV.1a - Identify the presence of relevant endogenically derived compounds [R1].

Requirements

	Baseline	Floor
Areal Coverage (km)	5 x 10	2 x 10
*Incidence Angle (°)	<45 at equator	
*Local solar time (hr)	9am – 3pm	
Spatial Resolution (m)	≤250	
Spectral Resolution (<2500 nm)	10 nm	
Spectral Resolution (2500-5000 nm)	20 nm	

*requirement drawn from science TM

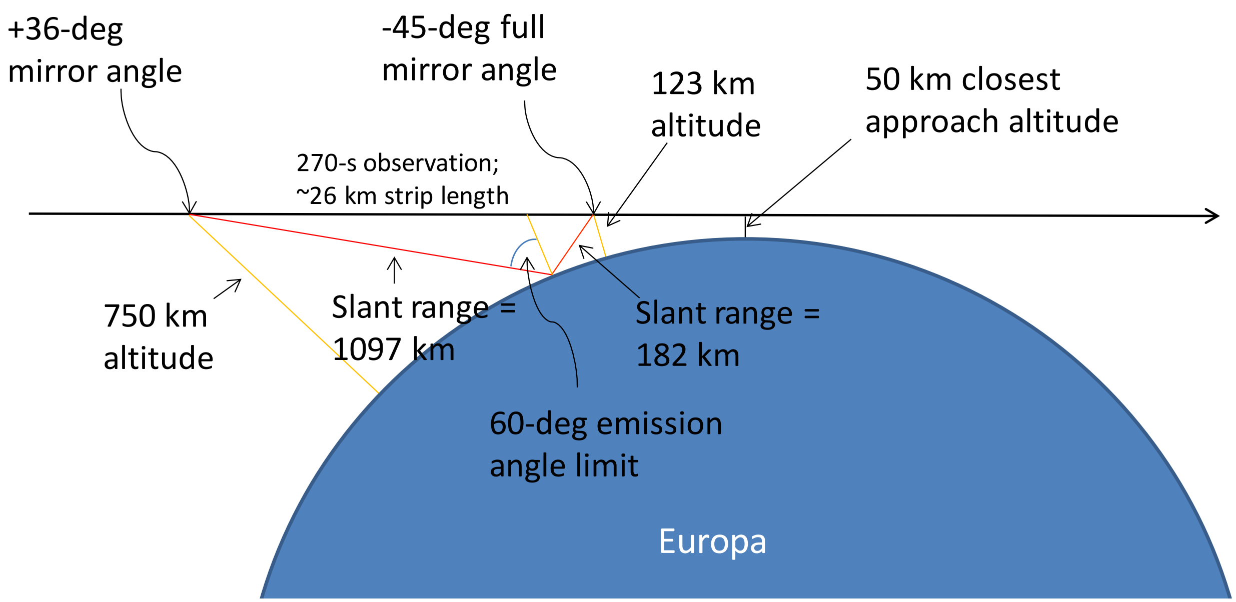
Shortwave Infrared Spectrometer (SWIRS)
ORIGINAL DESIGN

Instrument Description

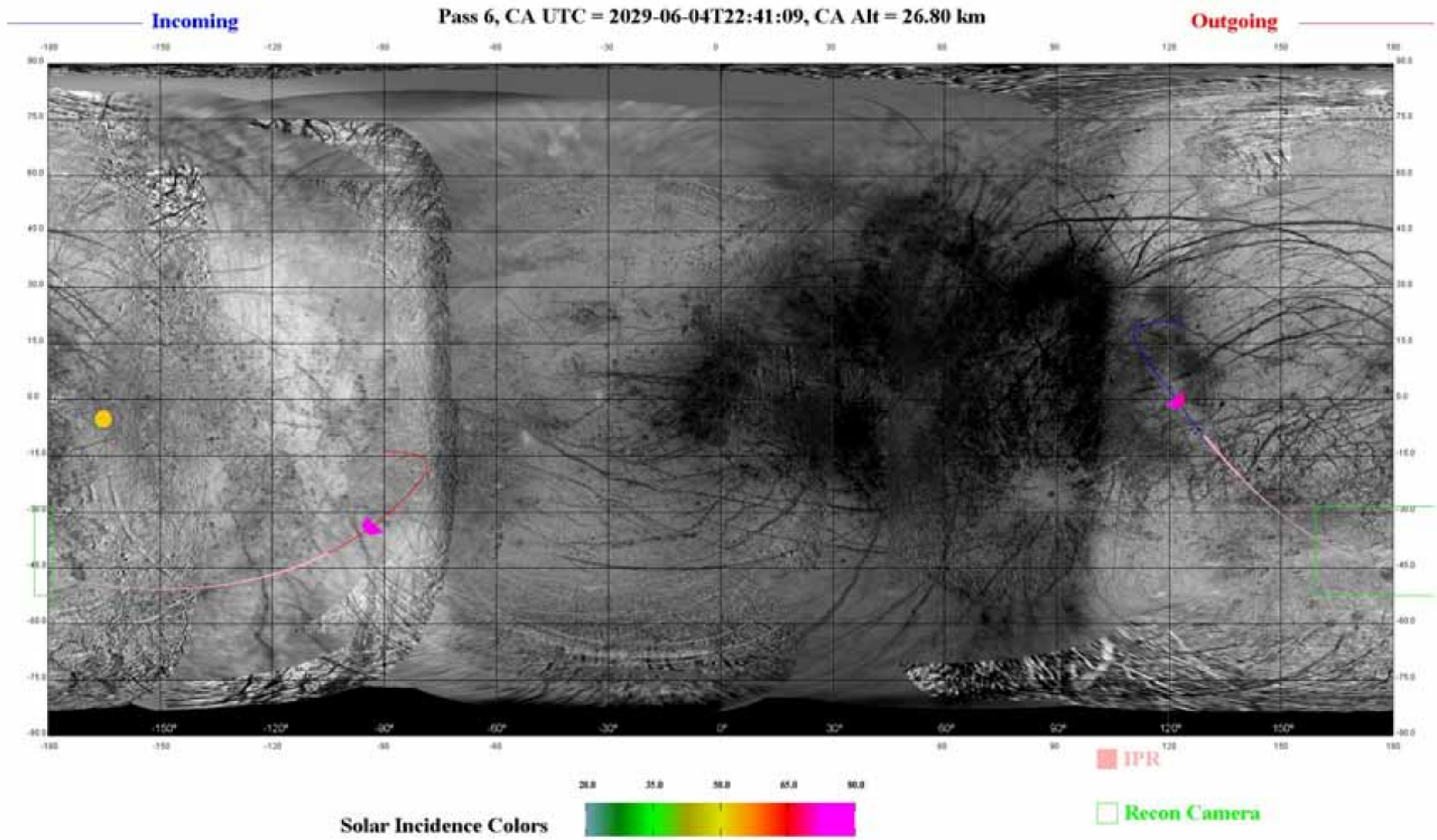
- Pushbroom spectrometer with single-axis along-track scan mirror system
- 640×480 HgCdTe detector with wavelength cutoff adjusted to 5 µm
- IFOV of 150 µrad
- Cross-track FOV of 72 mrad (4.1°)

Observing Scenario

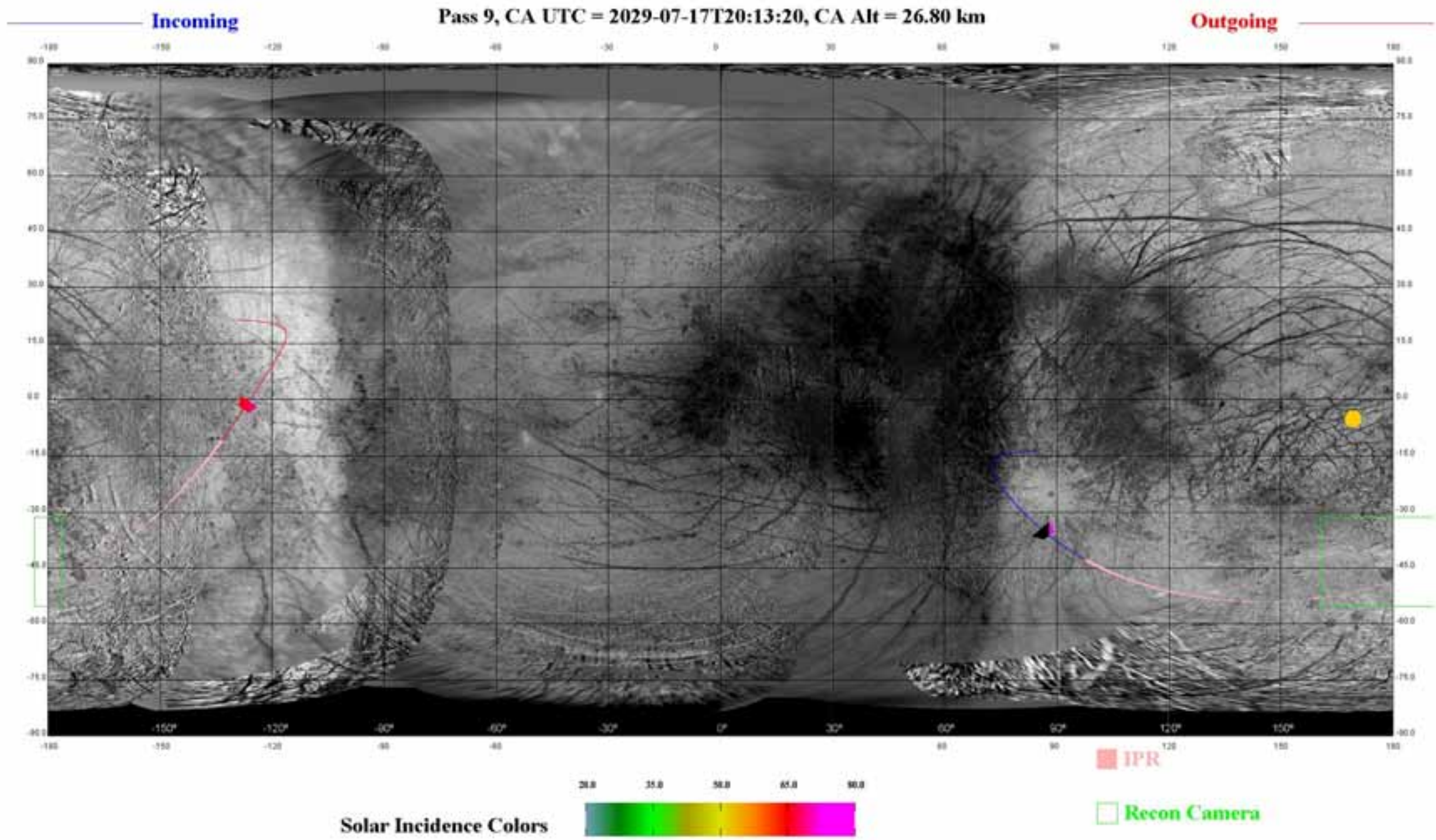
- Global-scale pushbroom coverage on approach and departure at ranges below 66,000 km altitude
- Pushbroom coverage of selected regions along ground track at altitudes below 2000 km



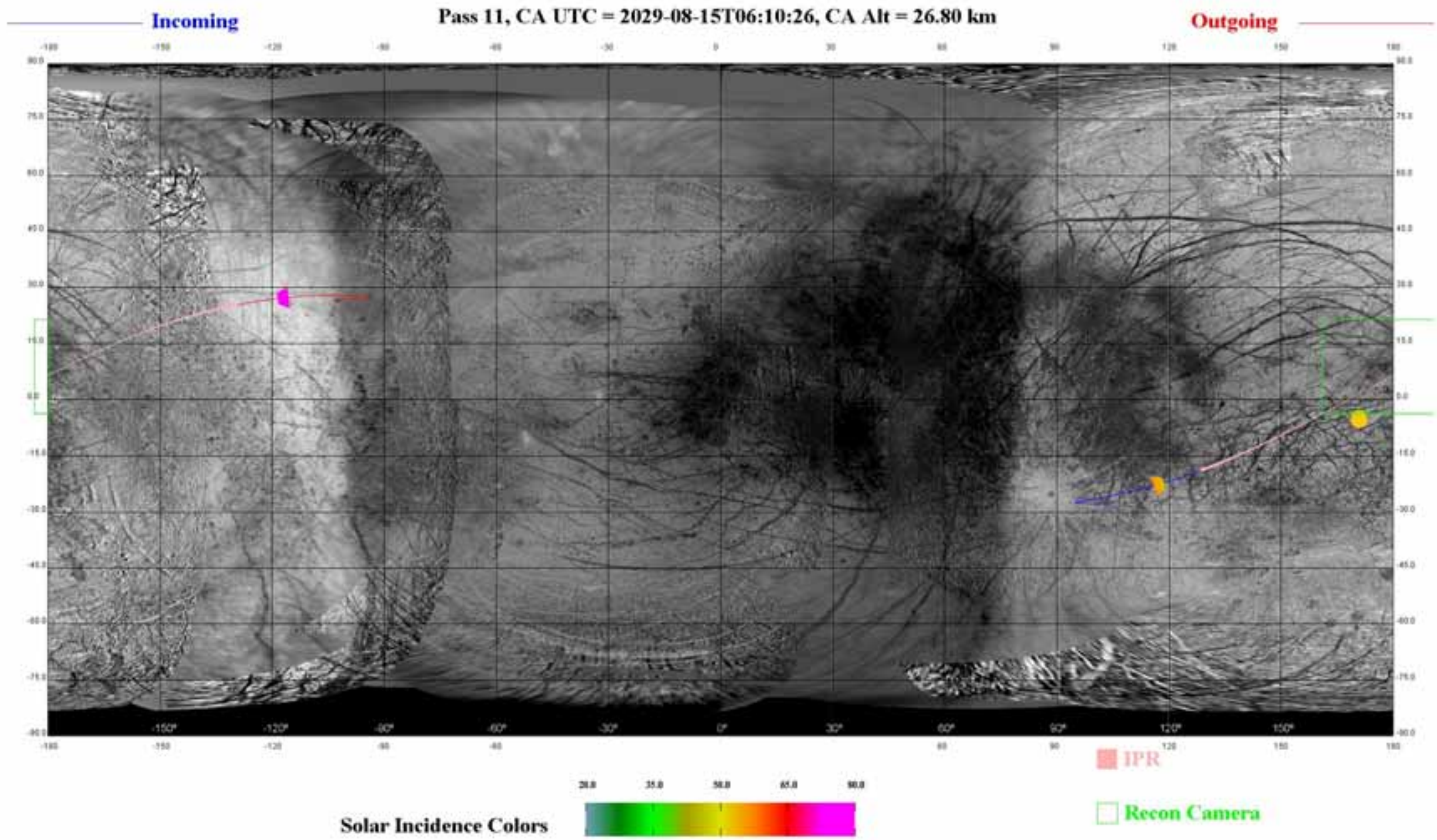
SWIRS - Flyby 6



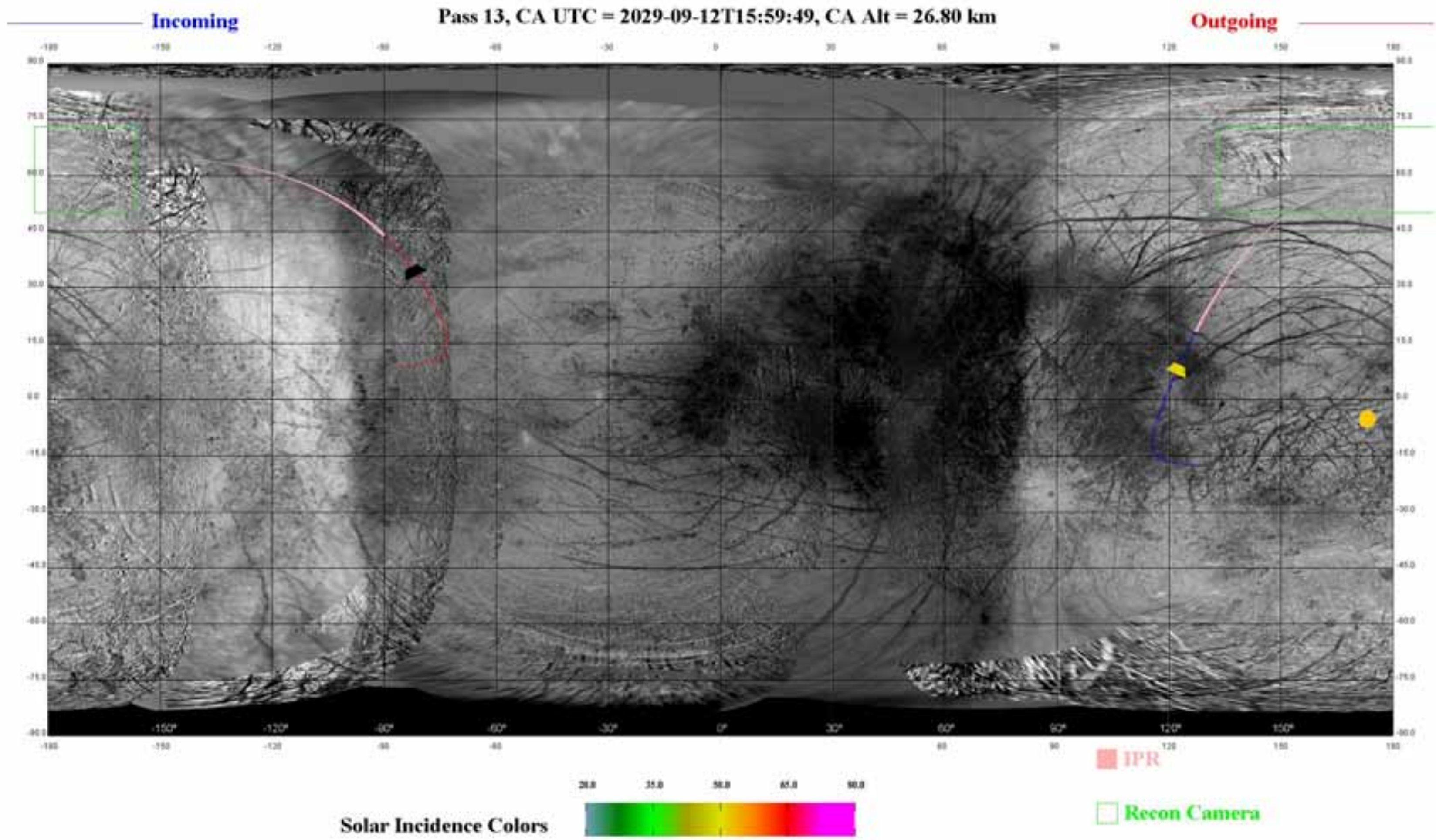
SWIRS – Flyby 9



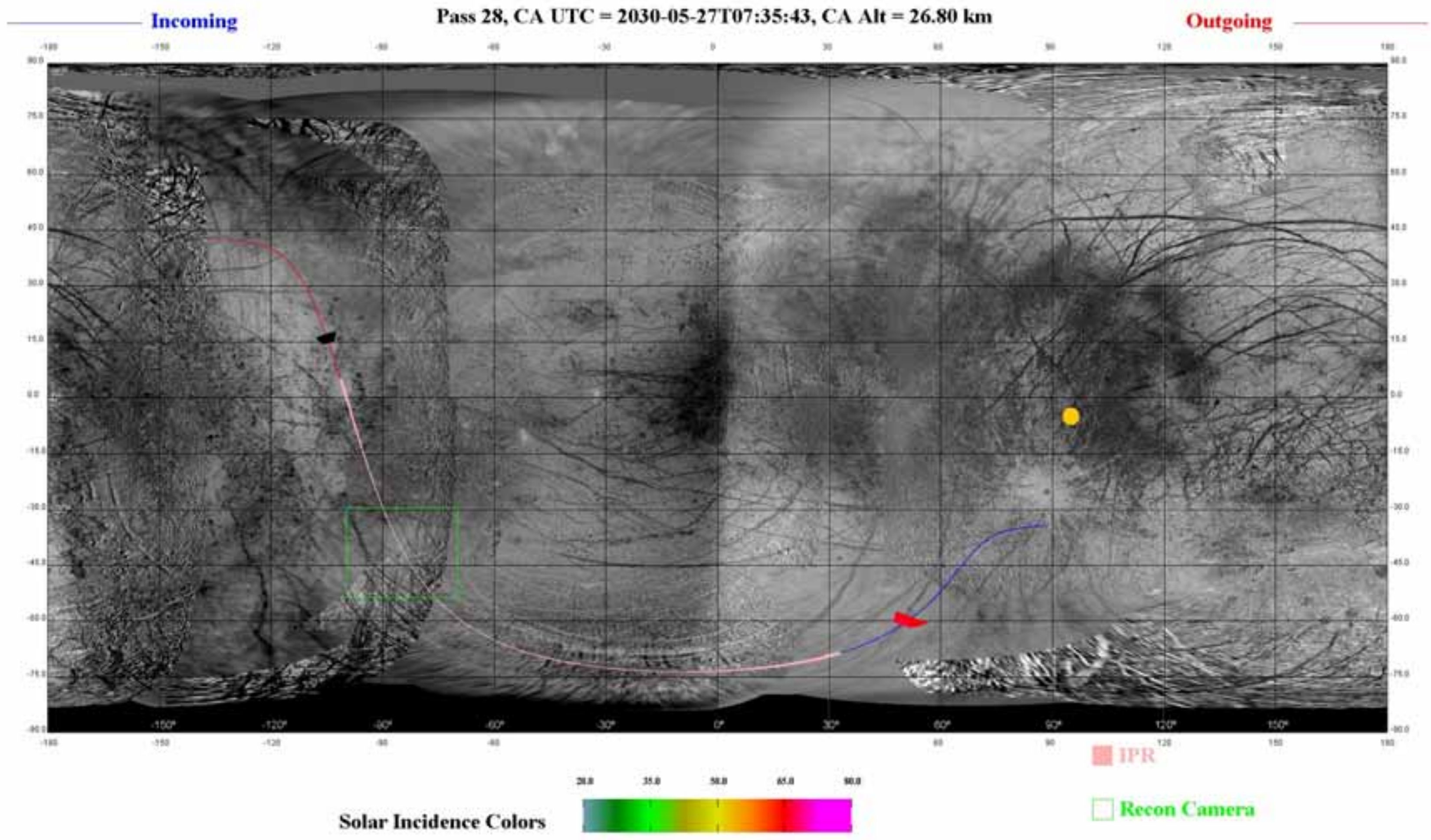
SWIRS – Flyby 11



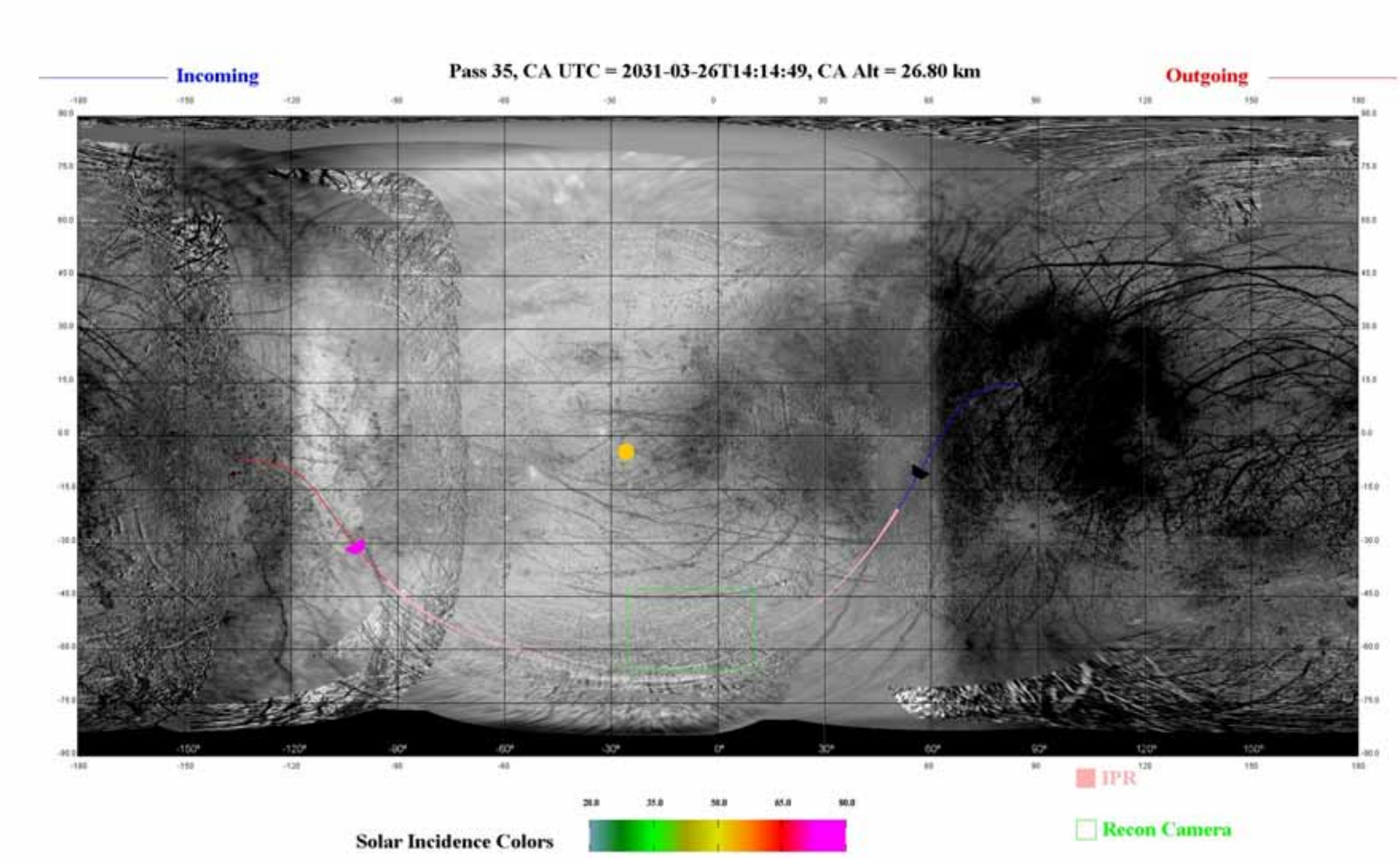
SWIRS – Flyby 13



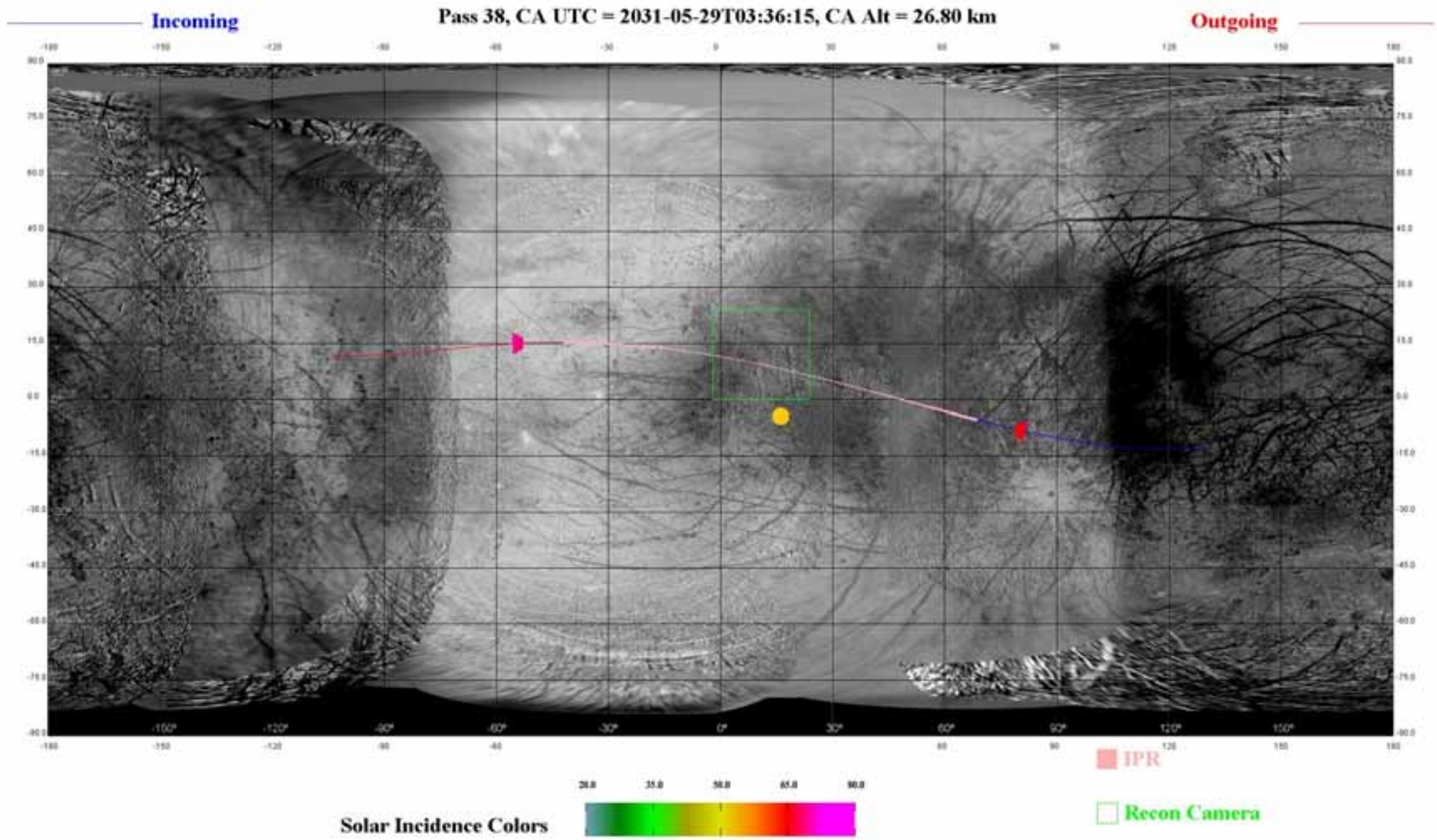
SWIRS – Flyby 28



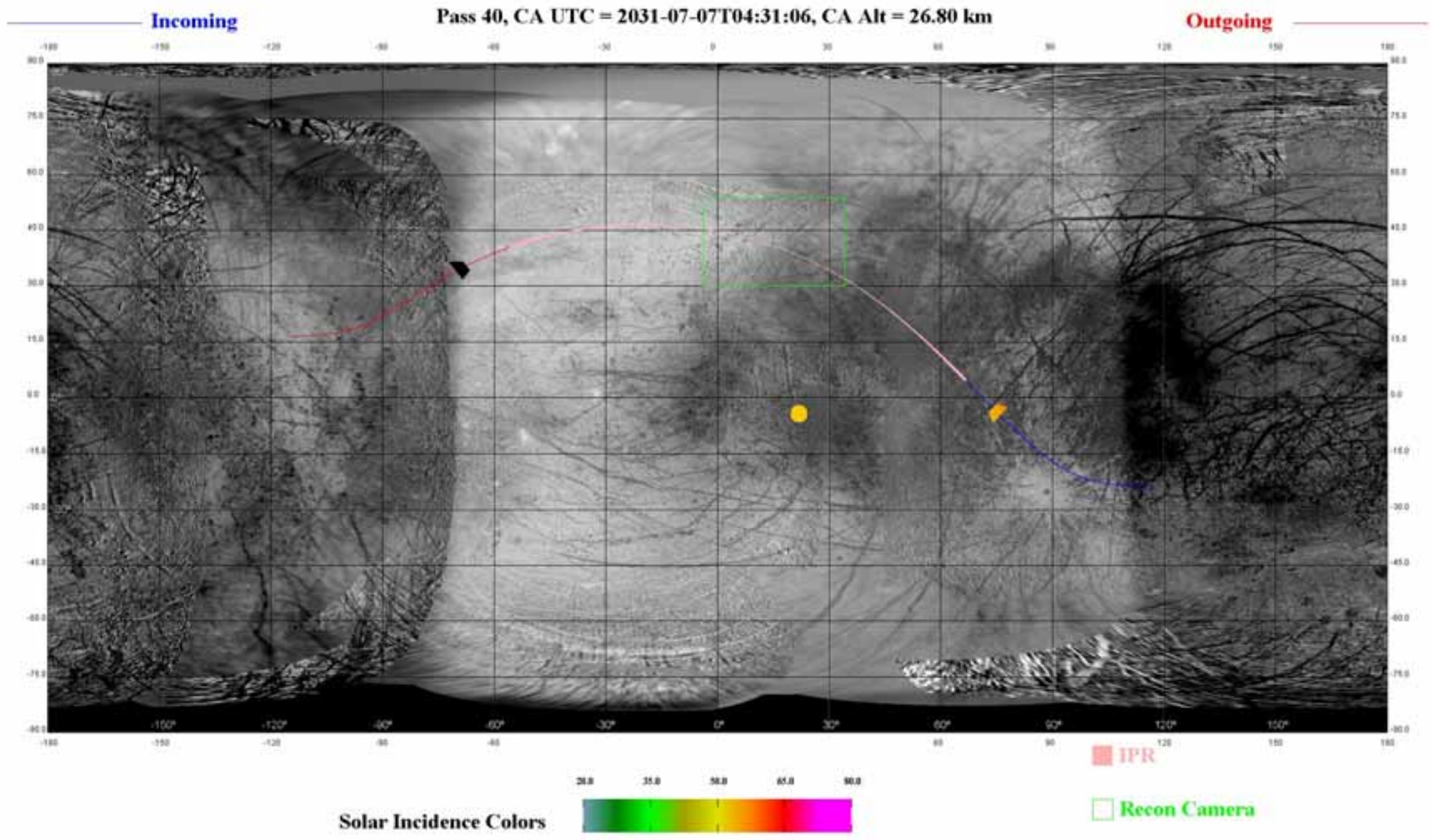
SWIRS – Flyby 35



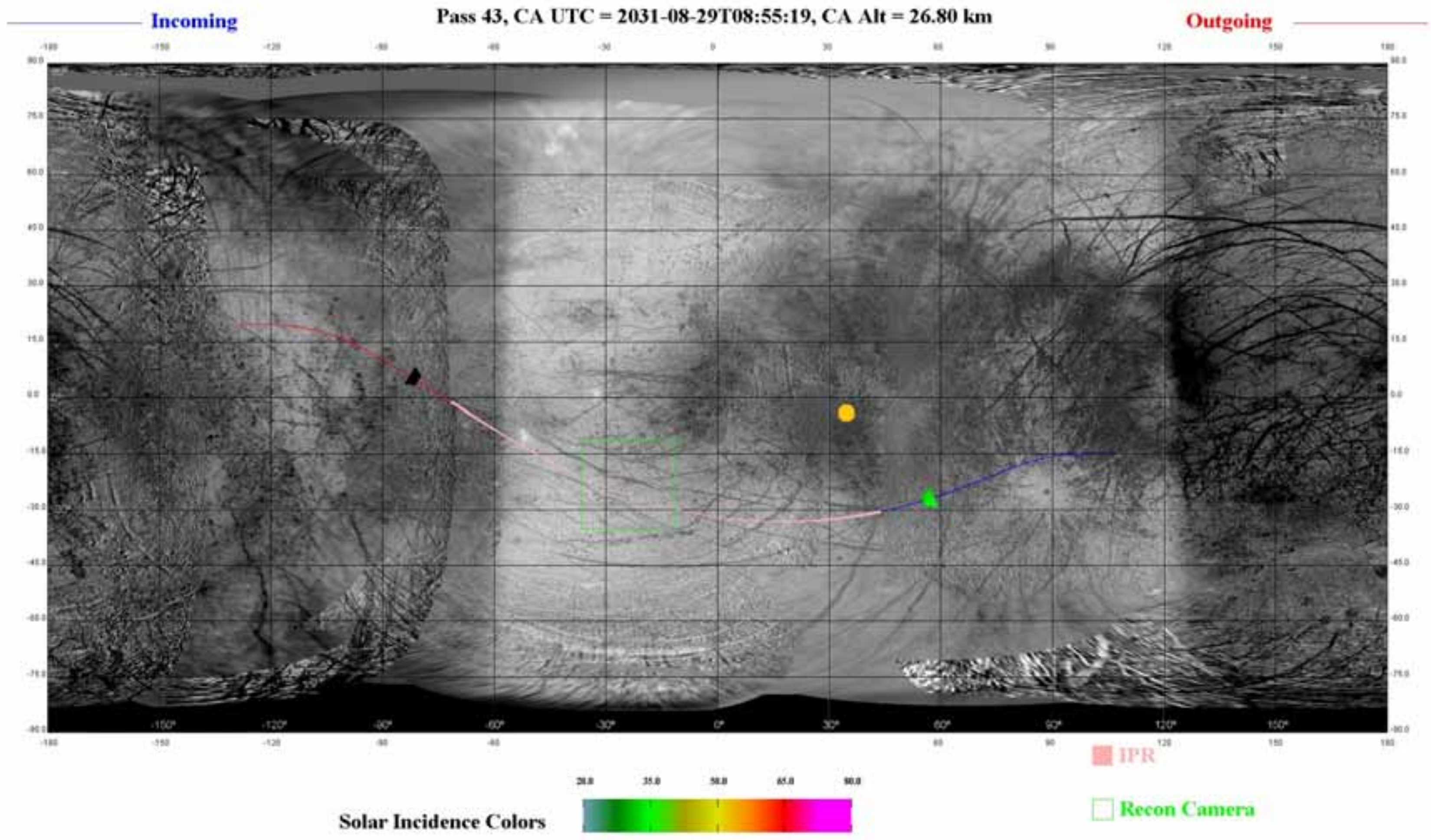
SWIRS – Flyby 38



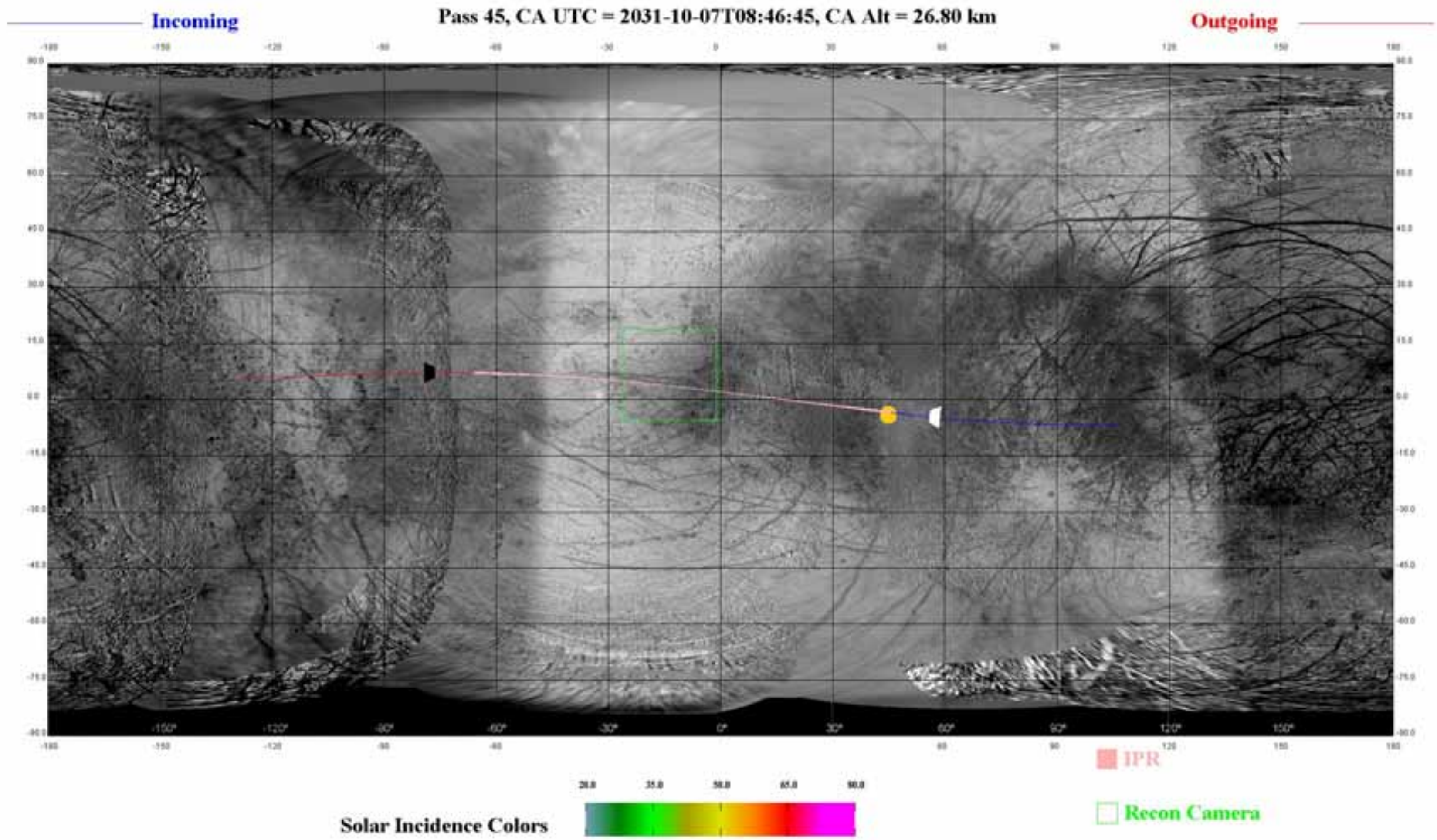
SWIRS – Flyby 40



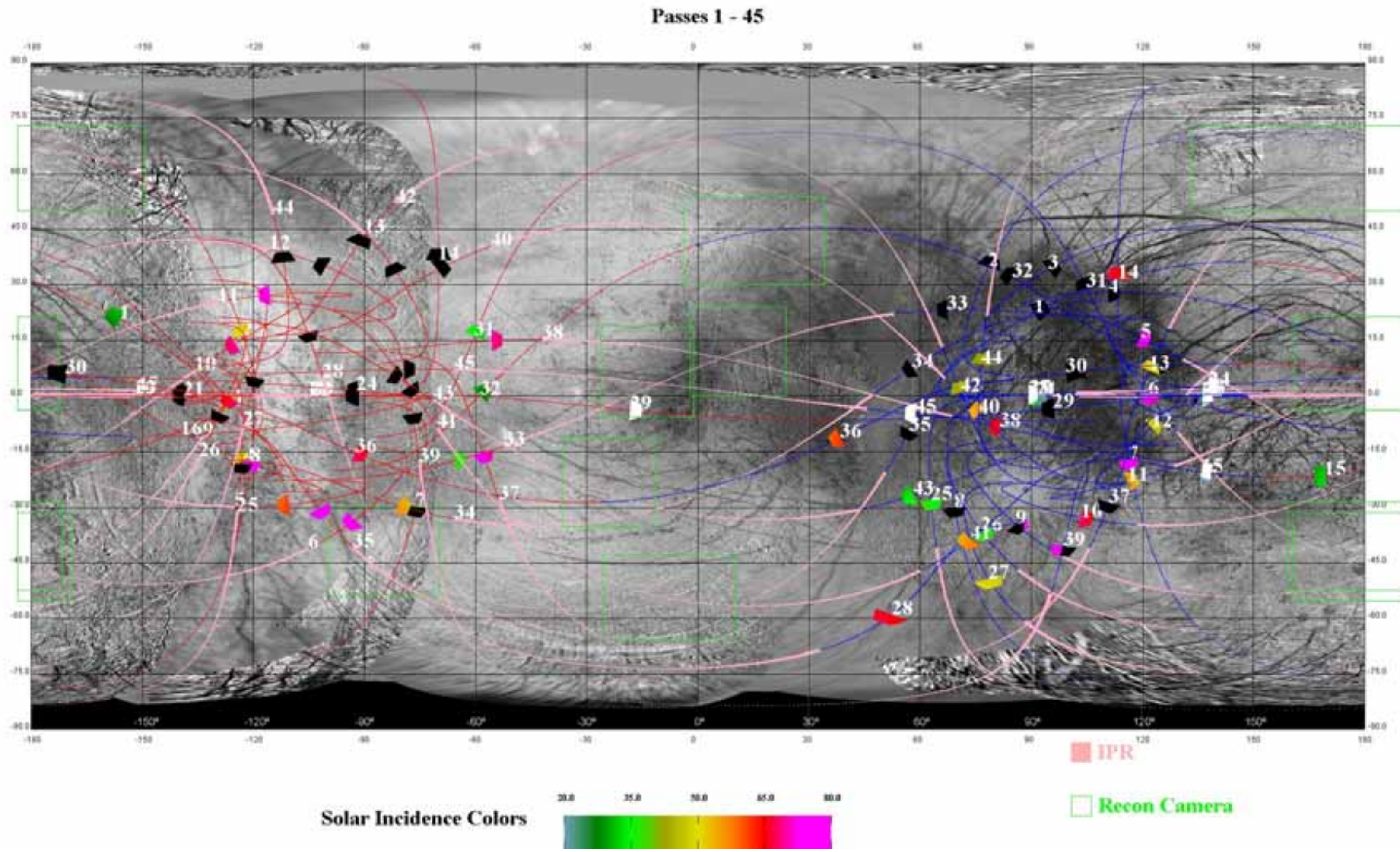
SWIRS – Flyby 43



SWIRS – Flyby 45



SWIRS – All 45 Flybys



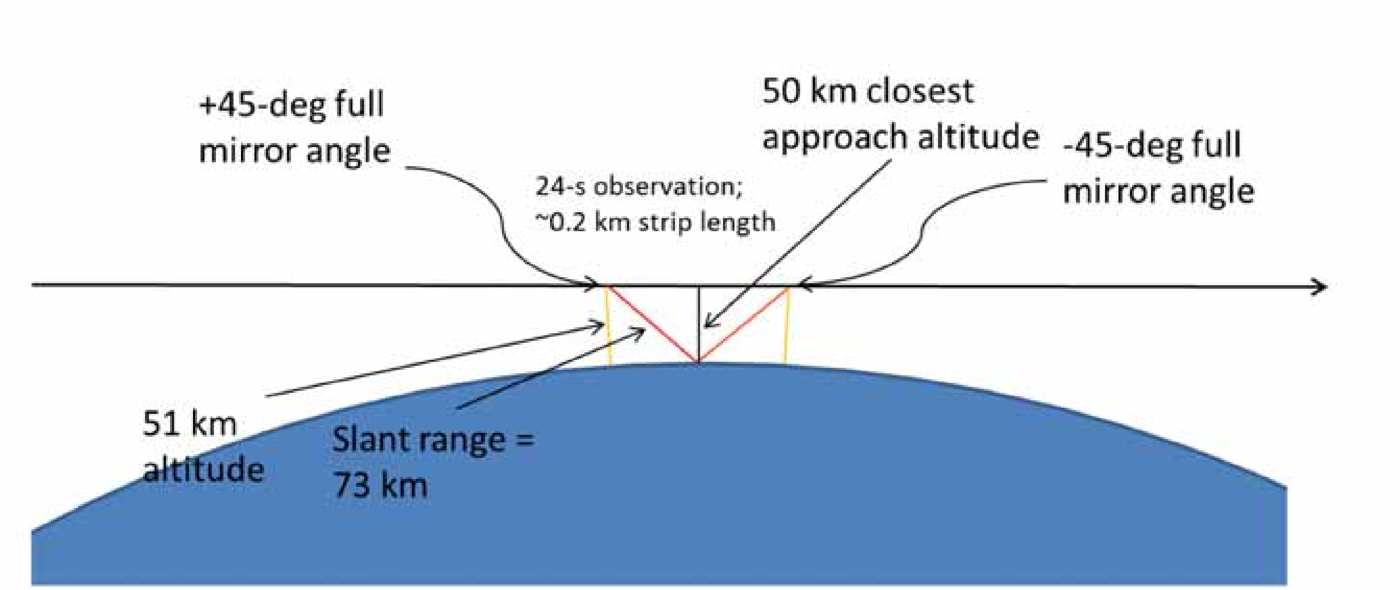
Shortwave Infrared Spectrometer (SWIRS)
PROPOSED REDESIGN

Instrument Description

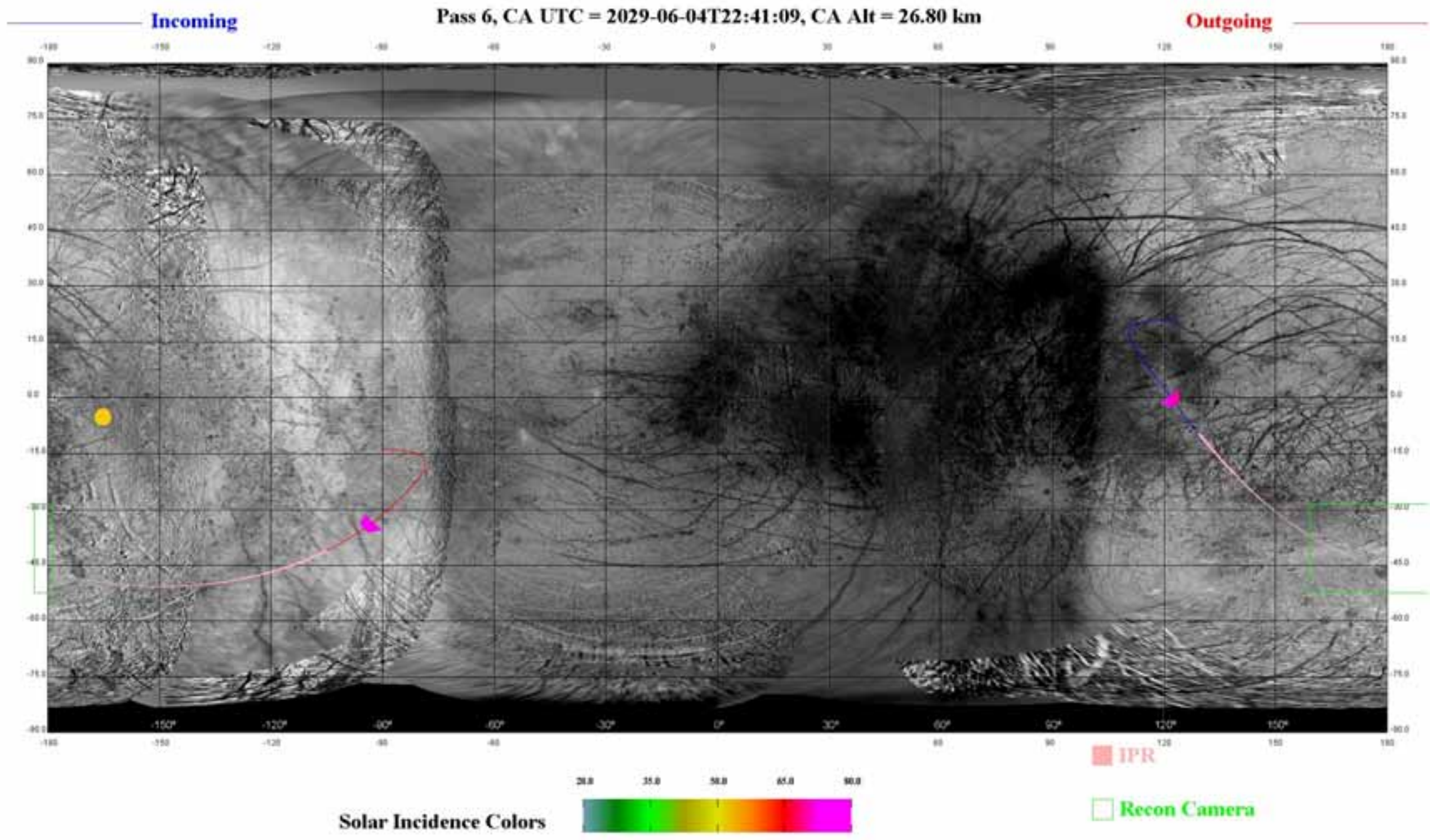
- Assumes 3x reduction in focal length:
- IFOV of 450 µrad
- Cross-track FOV of 216 mrad (12.4°)

Observing Scenario

- Global-scale pushbroom coverage on approach and departure at ranges below 22,000 km altitude
- Pushbroom coverage of selected regions along ground track at altitudes below 667 km

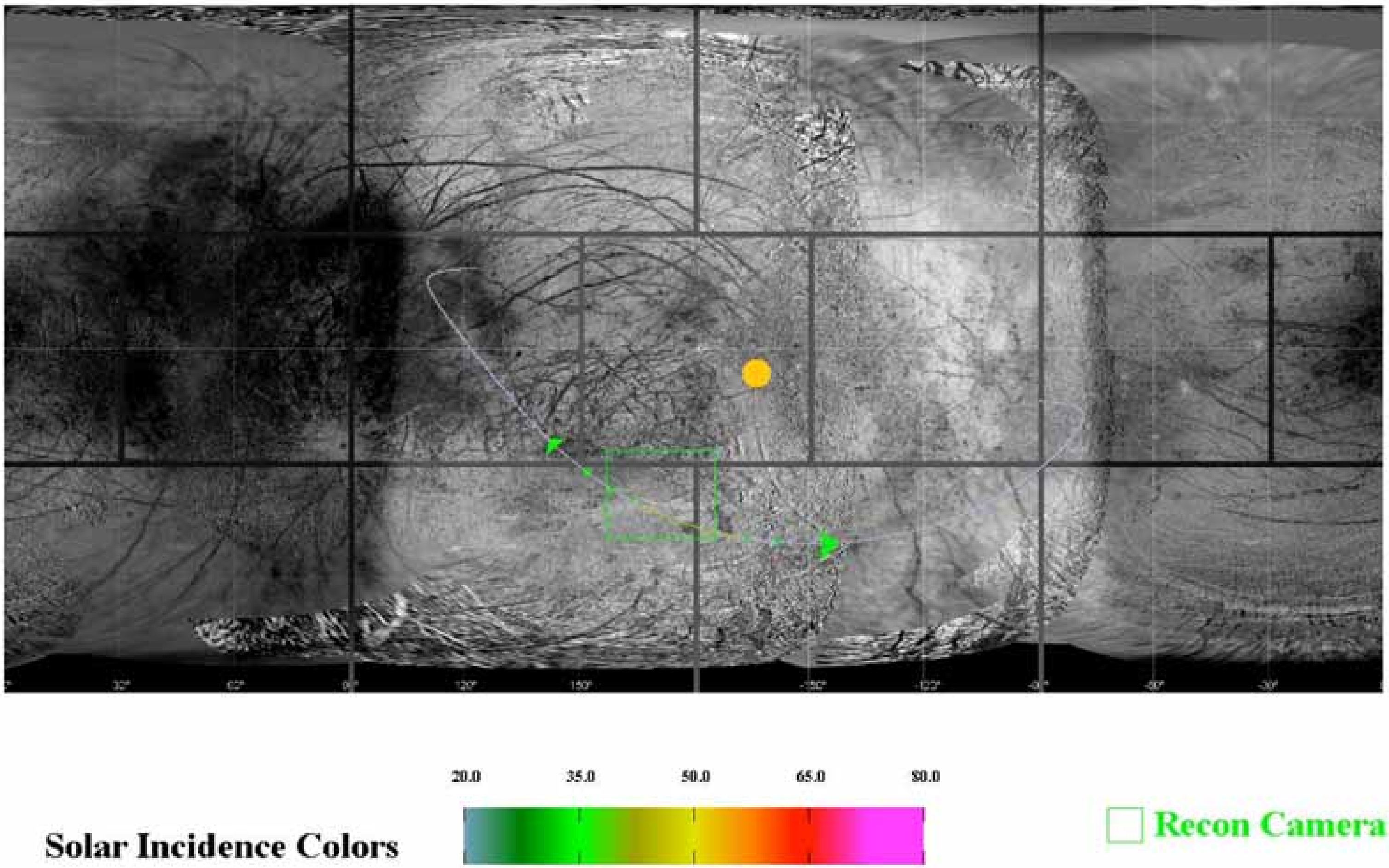


SWIRS - Flyby 6
– *previous design; poor incidence angle*

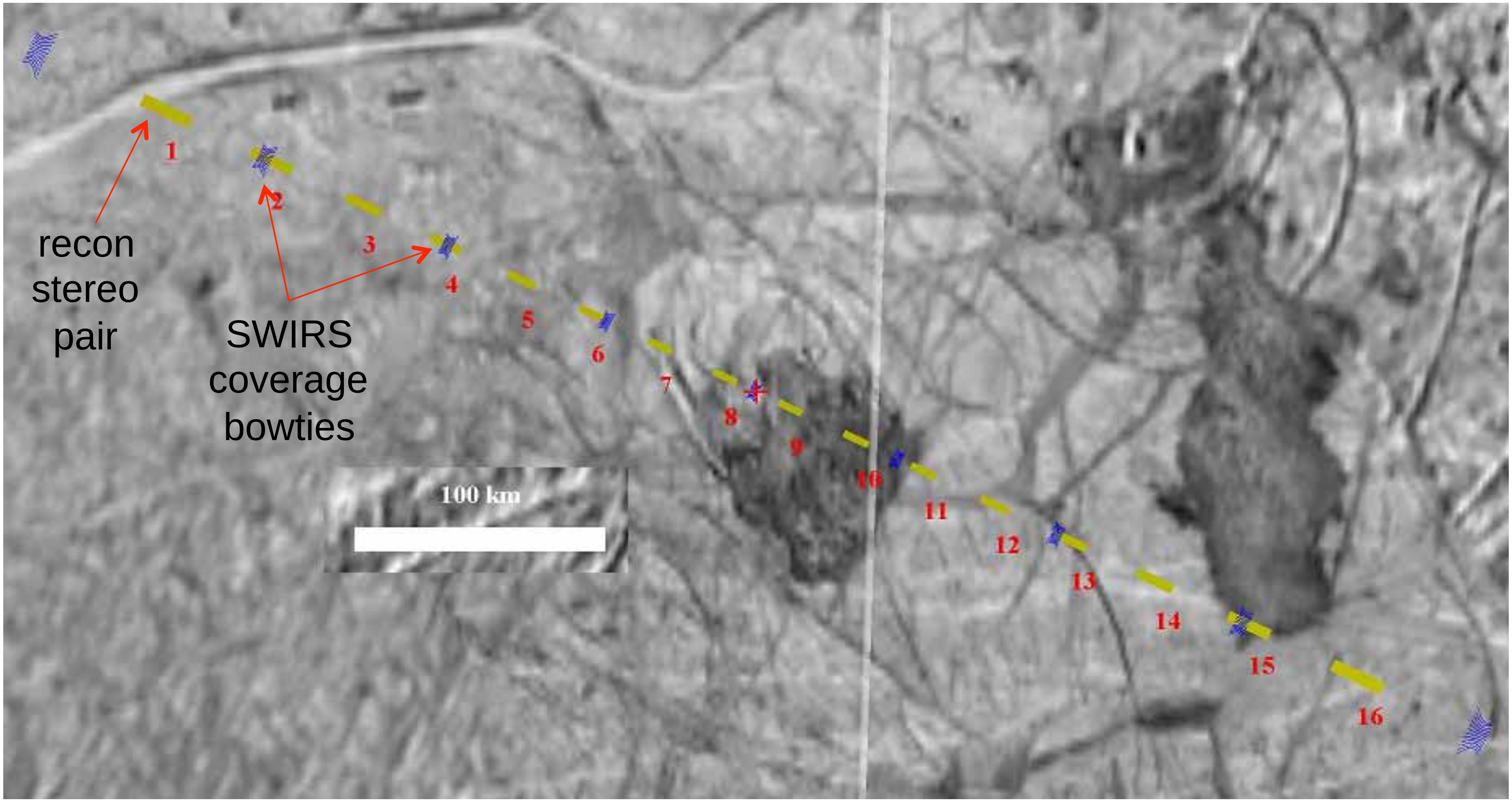


SWIRS – new footprints, flyby #6
= huge improvement in incidence angle

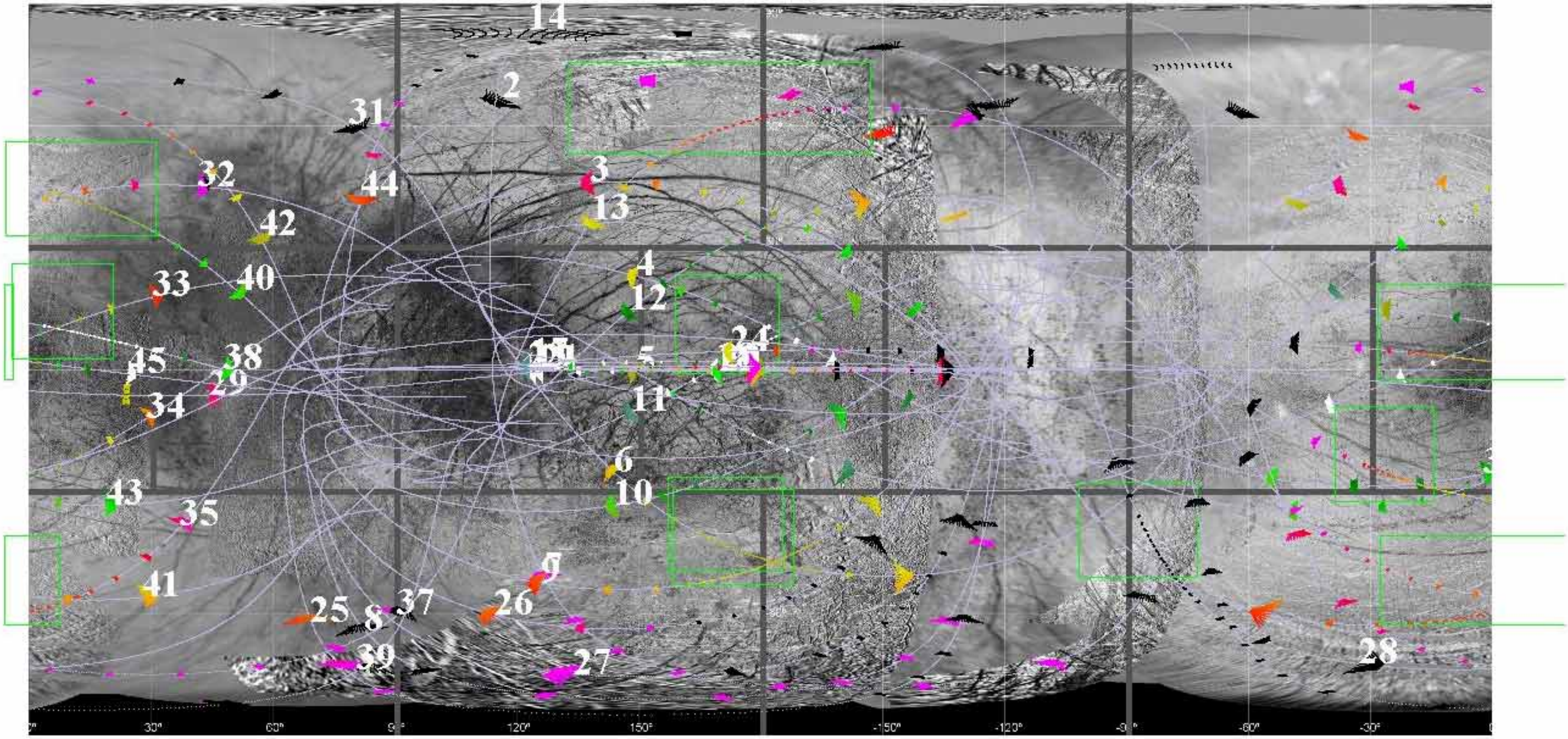
Pass 6, CA UTC = 2029-06-04T22:41:09, CA Alt = 26.80 km



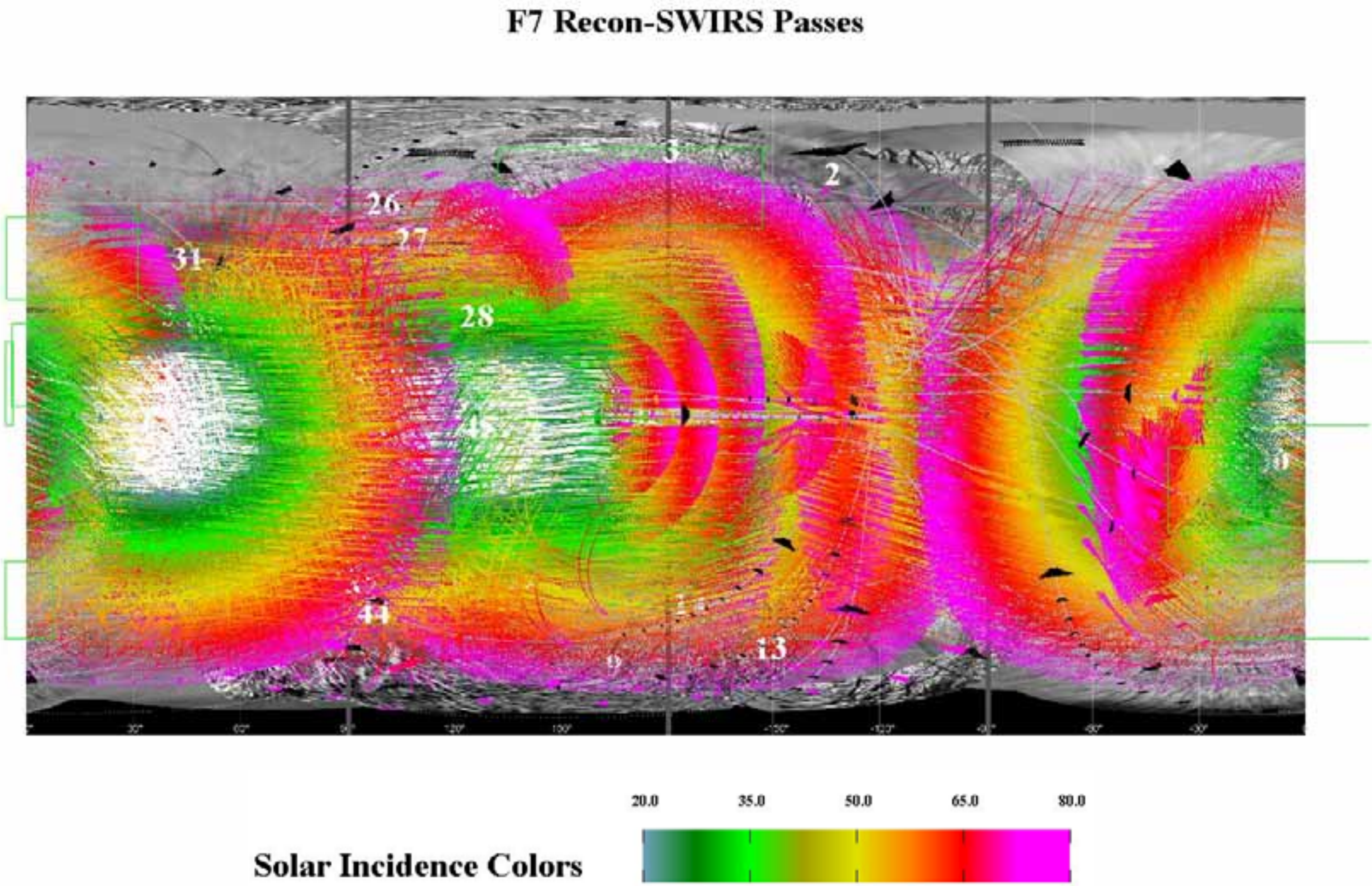
SWIRS – new footprints, flyby #6



SWIRS (hi res)+Recon, Recon Passes Only

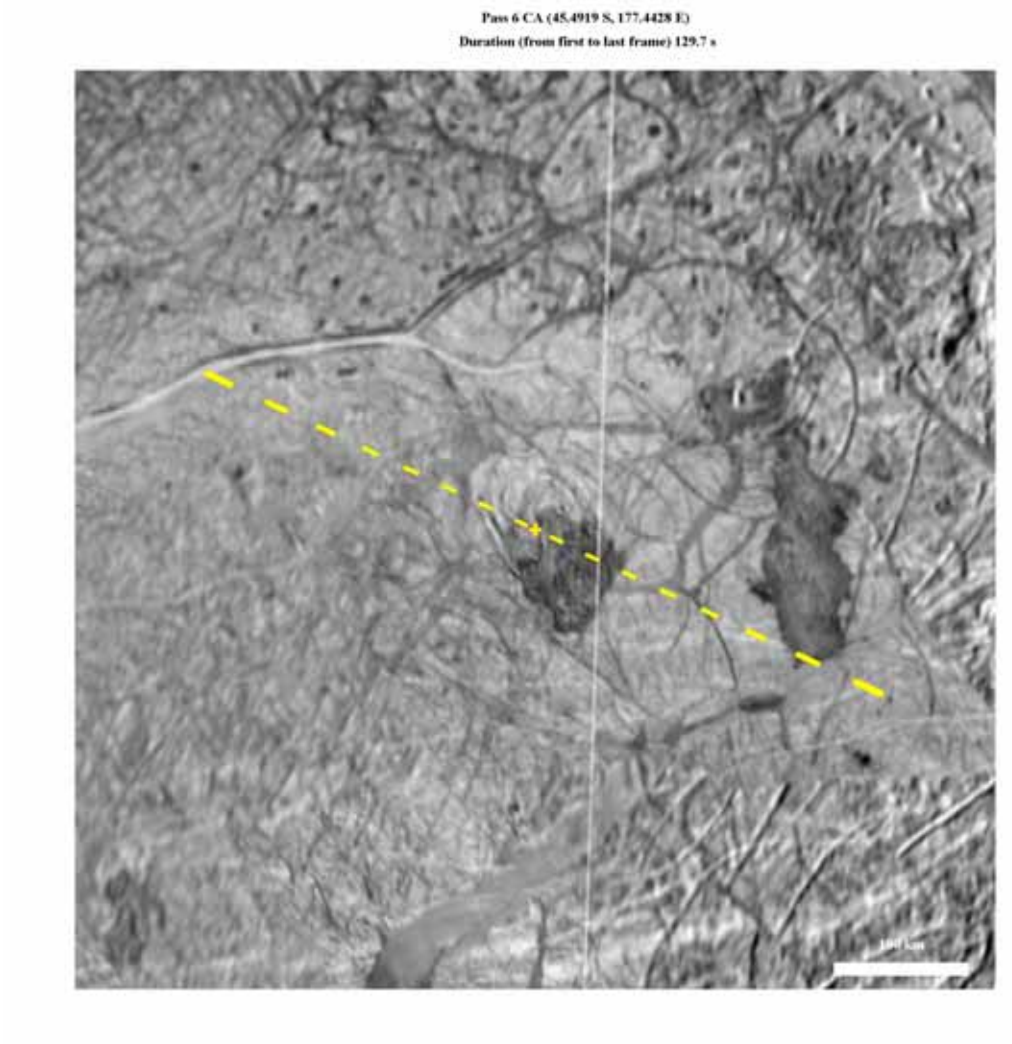


SWIRS Low Resolution Coverage, Passes 1 - 45

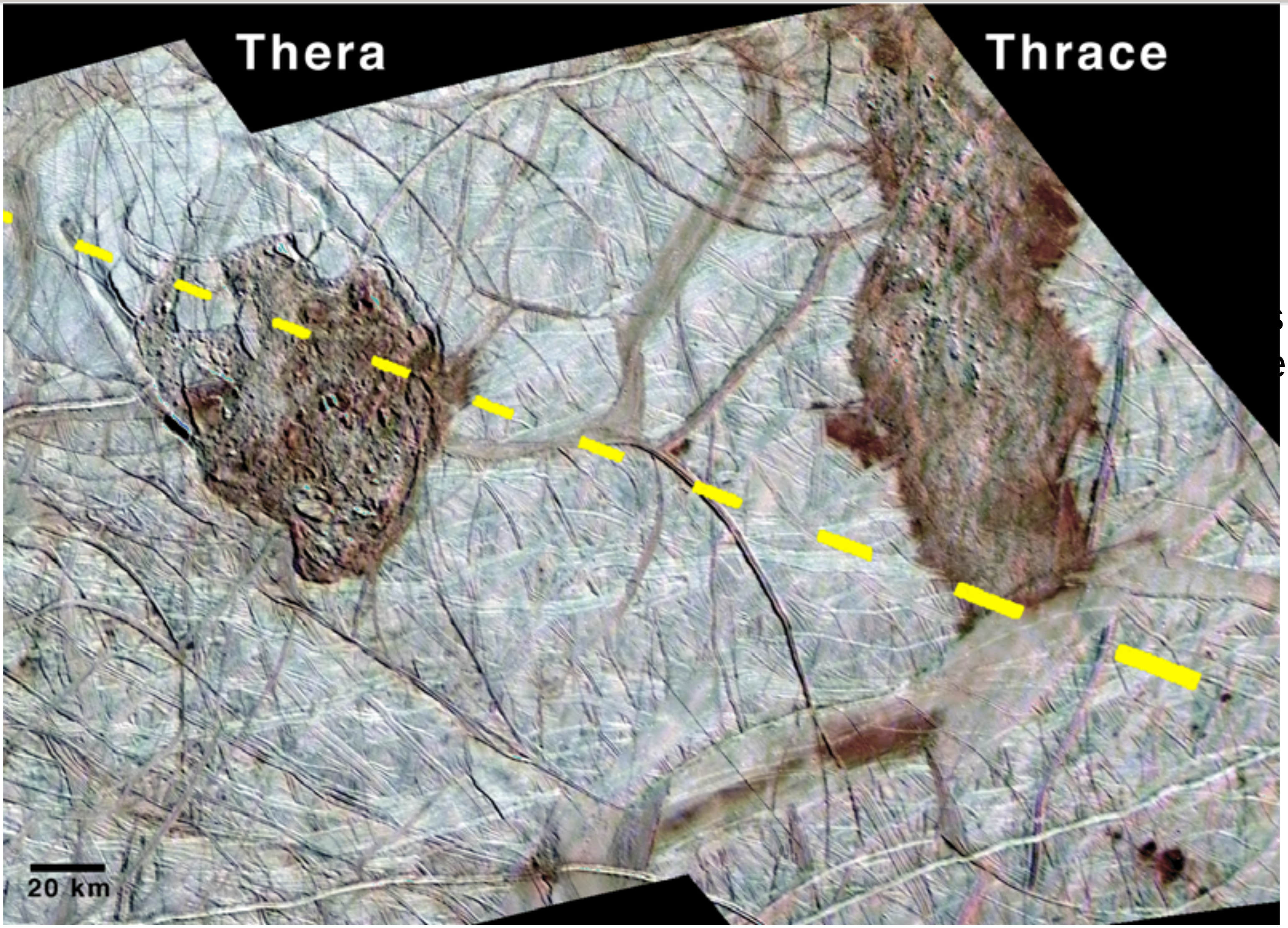


White < 20^{o}

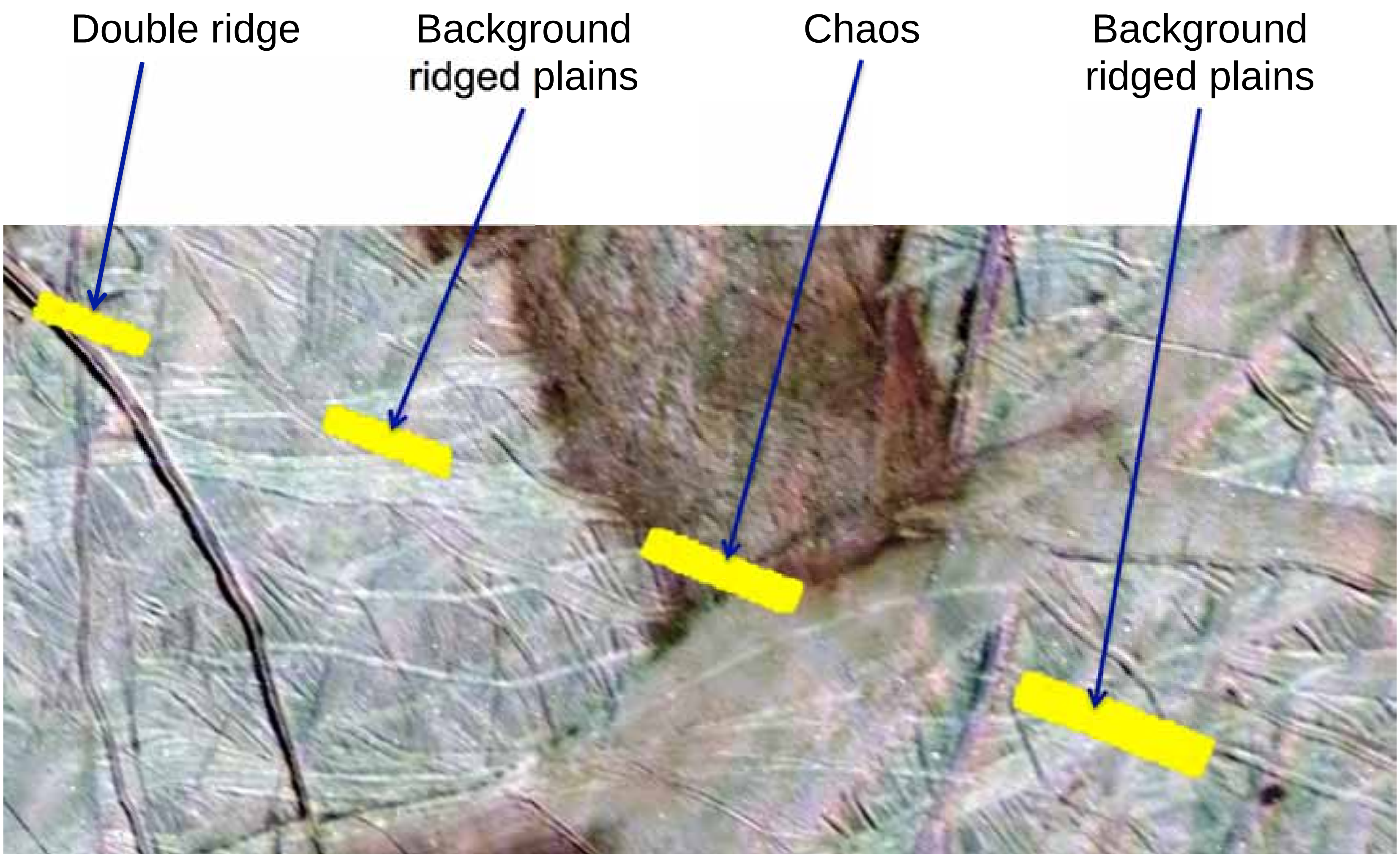
How many landform types do we image on one track?



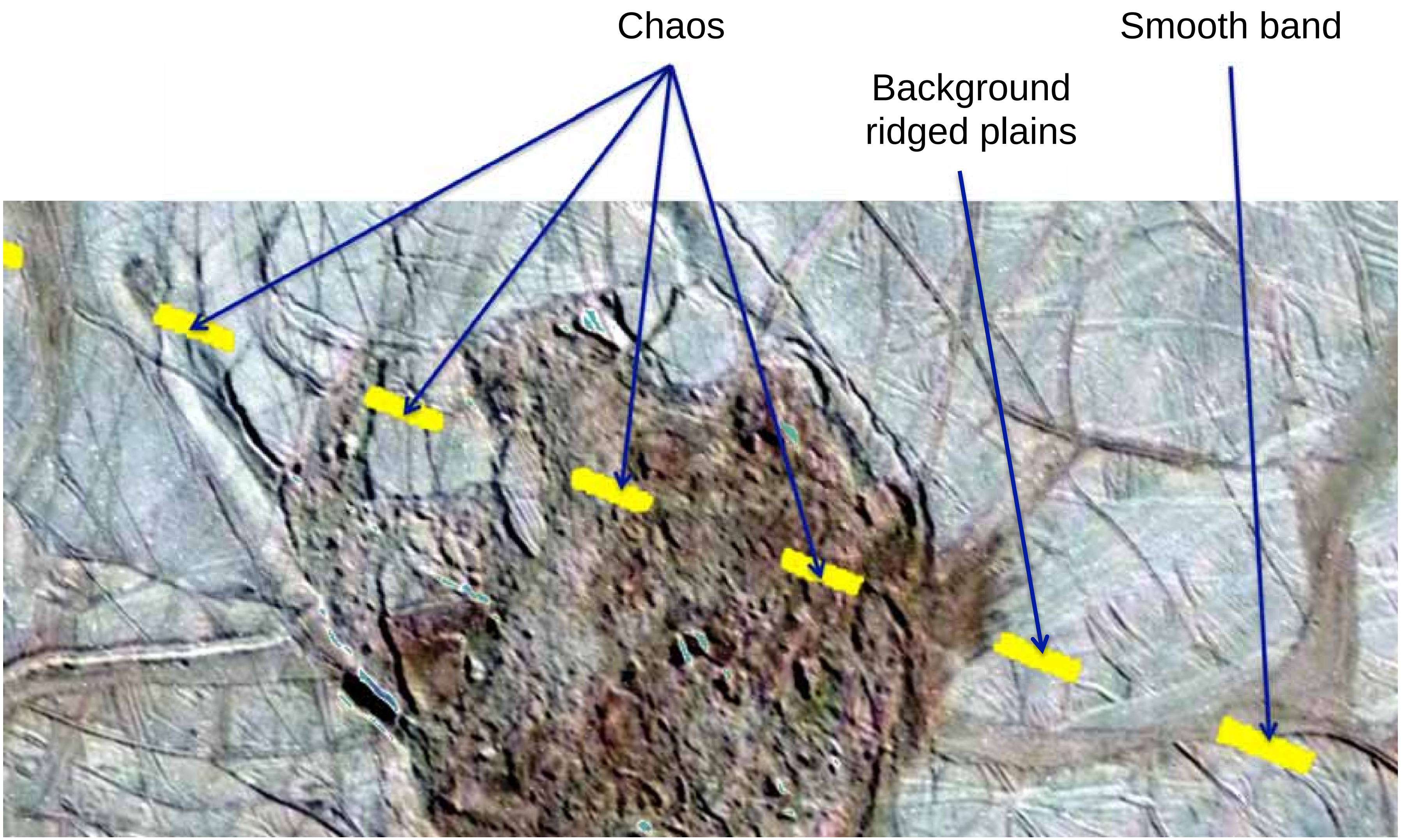
How many landform types do we image on one track?



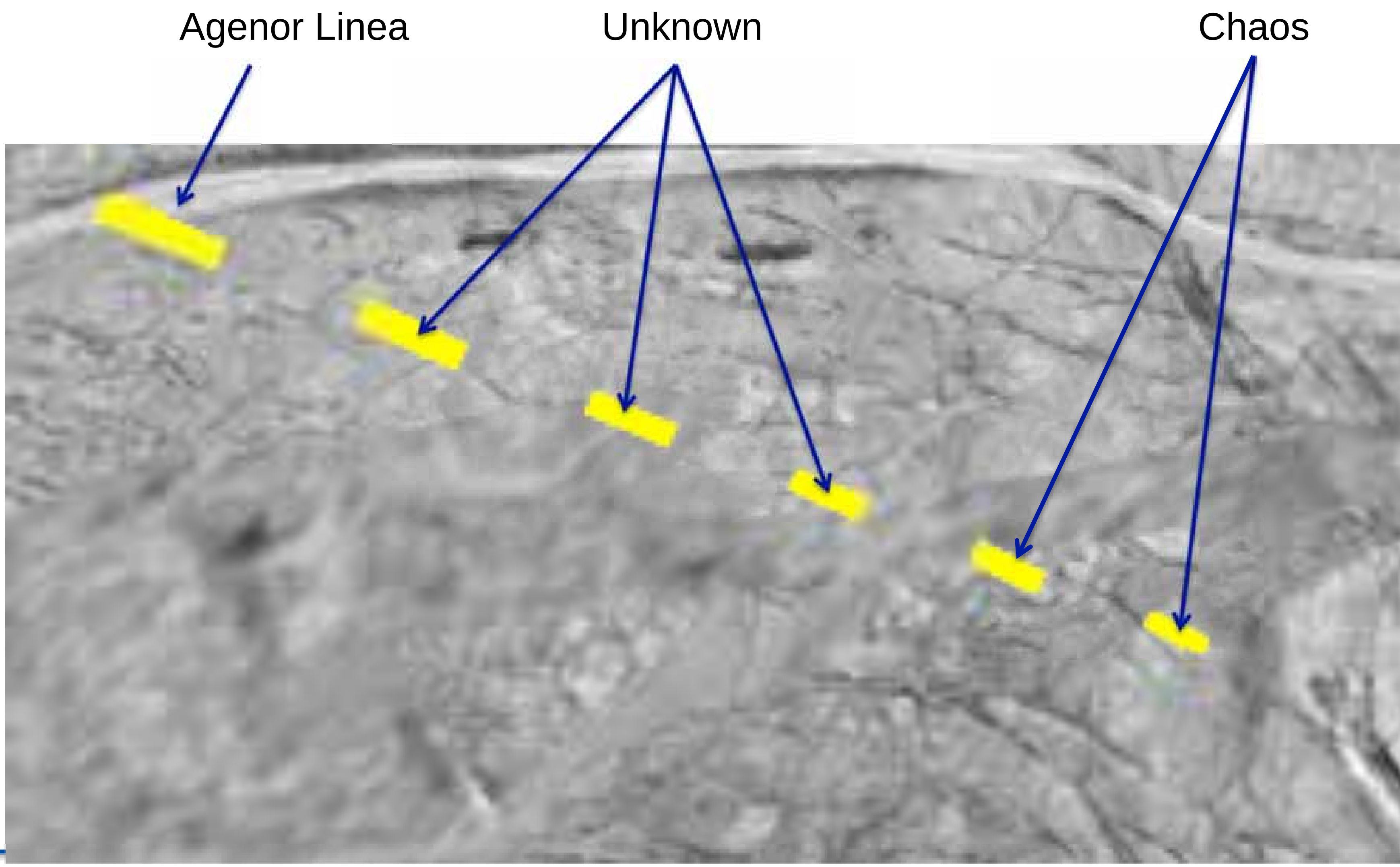
How many landform types can be imaged during one ~25 km altitude track?



How many landform types can be imaged during one ~25 km altitude track?



How many landform types can be imaged during one ~25 km altitude track?

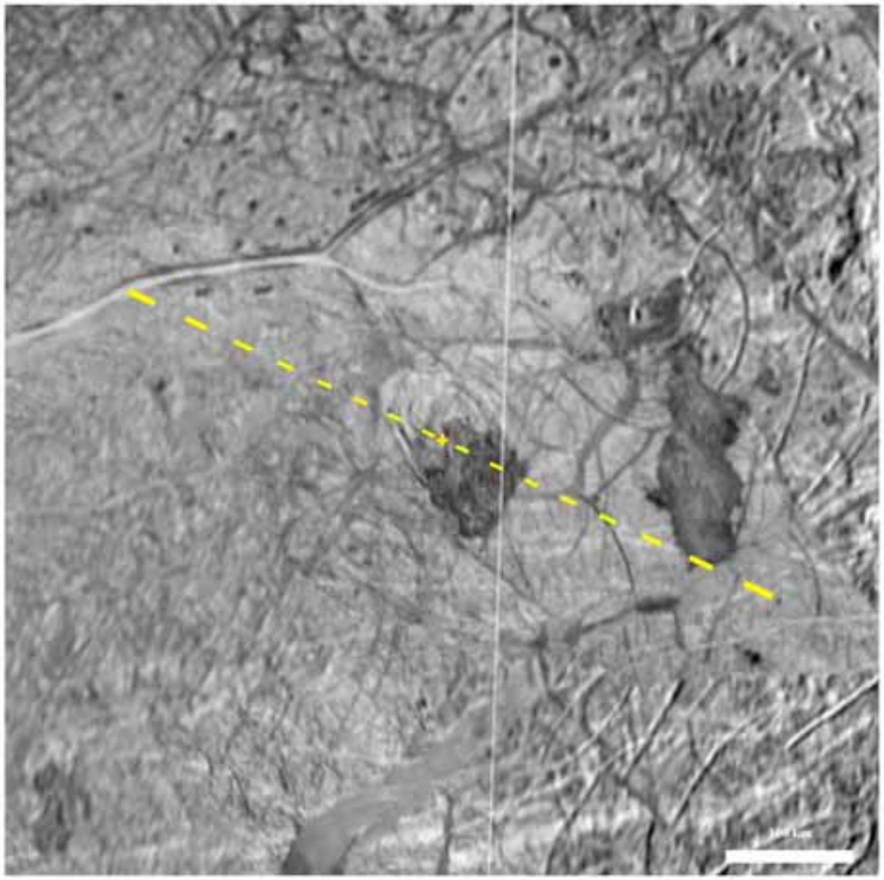


How many landform types can be imaged during one ~25 km altitude track?

Preliminary analysis of one low-altitude flyby suggests that landing ellipses of the following feature types can be characterized with the RC:

- Chaos – 7
- Background ridged plains - 3
- Smooth bands – 1
- Double ridge - 1
- Unknown – 3
- Agenor Linea (bonus)

Pass 6 CA (45.4919 S, 177.4428 E)
Duration (from first to last frame) 129.7 s



Summary

Accomplishments

- Drafted Reconnaissance justification document – in review
- Streamlined Reconnaissance traceability matrix
- Prioritized Reconnaissance measurements
- Defined what constitutes a “landform” and determined approximate coverage of different features by representative landing ellipses
- Performed initial evaluation of reconnaissance data acquisition in F7 trajectory (RC, ThI, SWIRS)
- Started investigation of SWIRS footprints with wider FOV

Summary of F7 trajectory

Preliminary investigation of the 13-F7 trajectory suggest the following:

- Recon camera measurements (Priority R1) could be made without impeding the science data collection
- Multiple landforms could be investigated on each flyby, lending confidence that 15 sites would be fully characterized
- SWIRS data collection may not meet the Recon measurement requirements – we are investigating a wider FOV
- Thermal imaging (Priority R2) is a challenge
  - Multiple sites could be imaged but only at one time of day; very few sites could be imaged more than once
  - Multiple sites could be imaged during 10am – 3pm, but they are limited to two ~30º longitude bands, 180º apart
  - Additional sites could be imaged if off-nadir pointing is employed

Plans for iteration 7 (1)

Focus area	Task
13-F7 tour evaluation	Complete evaluation of Recon camera coverage
	Complete evaluation of thermal imaging
	Complete evaluation of SWIRS coverage
	Evaluate topographic imaging
	Evaluate number and variety of landforms imaged
	Evaluate coverage of landforms in sites of high and low radiation exposure

Plans for iteration 7 (2)

Focus area	Task
Science and safety investigations	Reevaluate composition resolution requirements (with ESAG)
	Finalize definition and prioritization of RTM measurement requirements
	Investigate context imaging requirements
	Evaluate need for stereo high-res data at each landform – can some of groundtrack be acquired in mono?
Recon Conops	Complete a full 13-F7 conops for Recon to integrate with and balance with mission resources requirements